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THE ESTIMATION OF DAILY ESCAPEMENT AND TOTAL ABUNDANCE
FROM CATCH PER UNIT EFFORT OF THE SOCKEYE SALMON
FISHERY IN TOGIAK BAY, ALASKA

By

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ABSTRACT

Catch per unit of effort (CPUE) from the commercial sockeye salmon *(Oncorhynchus nerka)* fishery in Togiak Bay, Alaska had not previously been related to standing stock in a rigorous manner. It was proposed for the Togiak system that the regularity of fishing periods, the stability of effort, and the large percentage of the escapement counted on a daily basis should accommodate the use of CPUE in estimating daily abundance and total returning stock while the fishery is in progress.

A model was developed to estimate daily escapement as the difference between daily abundance and catch. Daily abundance was estimated as a function of daily CPUE and a catchability coefficient. The catchability coefficient was found to vary with the level of effort and a relationship was developed from historical data to estimate it in-season from the daily level of effort.

Total returning stock size was also estimated in the Togiak fishery model as the ratio of cumulative return to date over the expected proportion returned to date. The expected proportion was provided by a migratory time-density function derived as a historic average entry pattern for Togiak sockeye salmon.

INTRODUCTION

Background

The primary goal of the harvest management of sockeye salmon *(Oncorhynchus nerka* Walbaum*)* is to ensure a predetermined spawning escapement which includes all temporal and racial components of the run, yet efficiently utilizes the resource in terms of food production and revenue. In a large salmon-producing system such as Bristol Bay, Alaska, fisheries biologists have monitored sockeye salmon abundance at various life history stages for population estimates applicable to harvest control of commercial fisheries (Table 1, Figure 1). Initially the forecasting process uses counts of escapement from towers or estimates of spawning stock from aerial surveys to generate historical return per spawner data. The forecasting process continues with observations on subsequent life history stages. In the final stage, to verify the forecasts, test fishing programs have been developed from which catch per unit effort (CPUE) is related to total abundance of adults. Test fisheries have been set up outside the fishing districts, as off Port Moller near Bristol Bay, Alaska, to estimate incoming run strength and provide a daily passage rate. To estimate the extent of fulfillment of escapement goals, prior to verification at the towers, test fisheries have been established inside the rivers above the upper boundary line of the major fishing districts (Figure 1). These catches (or CPUE) provide timely estimates of the spawning stock which have passed through the fishing district and which will be counted from towers placed at the head of trunk streams. Much work has been done to quantify the CPUE of the test fisheries by standardizing the unit of effort and by compensating for the size selectivity of the gill net.

In contrast to the recent advances in the interpretation of test fishing data, commercial fishing CPUE data have not been well utilized in determining adult abundance. Often the short, irregular, and intense commercial fishing periods have resulted in commercial CPUE not being rigorously related to the standing stock. However, the fishery itself can provide valuable information on daily abundance and the entry pattern of salmon runs. In addition, in smaller systems where budget restraints or fishing revenue negates the use of test fishing programs, CPUE from the fishery may be the only indication of incoming run strength. Again, counting towers are often far removed in space and time from the commercial fishing district (Figure 1). If a substantial gap in time exists between the exit of sockeye salmon from the commercial fishery and the subsequent appearance of the same fish at the towers, CPUE of the fishery may provide the necessary and timely information on the status of fulfillment of the escapement goal. Thus, a quantitative approach is needed to relate commercial CPUE to daily abundance and total run size and further to explore the use of such relations in forecasting during the fishing season.

Given a fishery with extended fishing periods, a standardized unit of effort and daily escapement enumeration, the resulting CPUE would reflect both daily abundance and the time distribution of abundance. Extended fishing periods minimize the need to interpolate for data during periods closed to fishing. Daily escapement is the difference between daily abundance and catch. Given that the entry pattern or time distribution of abundance is a stable characteristic maintained through generations, this migratory behavior can be modeled in

Table 1. A chronological presentation of forecasting and harvest management data available for the management of Bristol Bay sockeye salmon.

Life stage of the sockeye salmon	Monitoring device	Estimator	Possible application
Escapement	Tower counts Weir counts Aerial surveys	Direct count	In-season management and subsequent forecast
Egg deposition	Egg pump	Average egg density	Forecast
Fry Age 0 Age I	Townetting	Fry index (CPUE)	Forecast
Smolt Ages I & II	Sonar counts	Direct count	Forecast
Immature ocean	Japanese high seas fishery	CPUE	Forecast
Mature ocean	Japanese high seas fishery	CPUE	Forecast
Returning adults	Interceptive domestic fishery	Qualitative indication of run strength	Qualitative verification of forecast
Inshore return	Port Moller test fishery	CPUE/return per index	Estimate total inshore run and daily passage rate
	Outside line test fishery		Daily management
	Commercial fishery	CPUE	Develop for daily management and estimation of total run size
Escapement	Inside test fishery Sonar counts	CPUE Direct count	Daily management

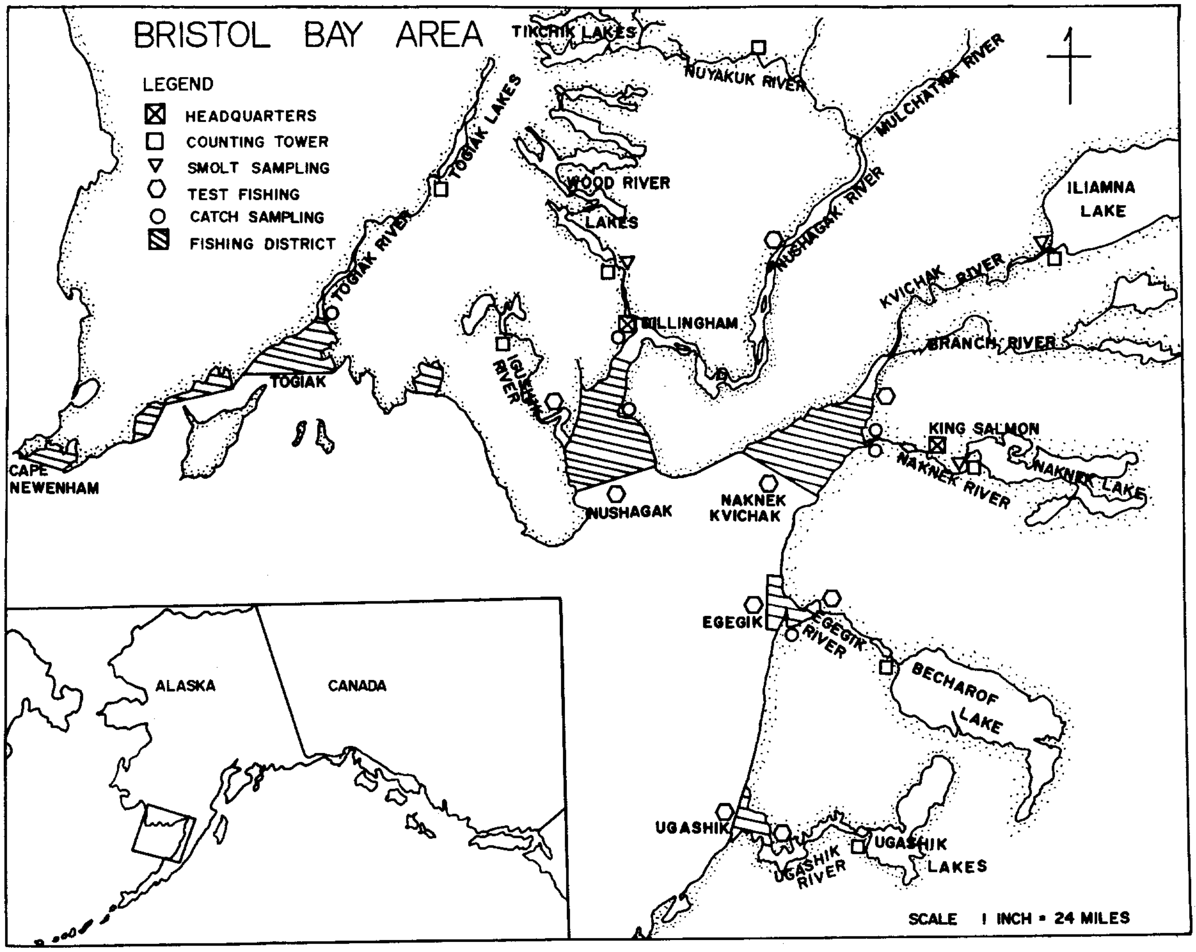


Figure 1. Fishing districts and sampling programs in Bristol Bay, Alaska.

terms of proportion of total abundance as a function of time. Elsewhere the resulting model has been termed a "migratory time-density function" (Mundy 1979) and from which in-season estimates of total run size can be obtained (Mundy and Mathisen 1981). Thus, a study resulting in a model incorporating daily CPUE from the commercial fishery and migratory time-density theory would provide managers with a daily escapement schedule, run timing, and an in-season estimate of total run size, all of which are vital to accurate harvest control.

The sockeye salmon fishery in Togiak Bay, adjacent to Bristol Bay, lends itself to such a study. Fishing is allowed in Togiak Bay inside a line from Rocky Pt. to Aeolus Mt. which comprises the Alaska Department of Fish and Game (ADF&G) statistical catch area, the Togiak River Section (Figure 2). This is not to be confused with the Togiak District which includes the additional terminal area fisheries of the Kulukak, Osviak, and Matogak sections. In Togiak Bay, fishing periods are set in advance and adjusted in accordance with in-season estimates of run strength and escapement levels. The normal period lasts from 9 a.m. Monday through 9 a.m. Friday. The fishermen are predominantly local residents and effort has increased only slightly since 1967 (Table 2). Registration information is as yet unavailable for 1979 and 1980, though fish ticket data show the maximum number of ADF&G set net license holders selling prior to 15 July, to be 41, while drift net licensees number 121 (Table 2). Based on the past relationship of registration to maximum observed effort, an increase in registration to 139 drift permits and 67 set net permits is indicated at the end of the 1978 season. Most (91%) of the fleet through 1978 was composed of skiffs having keels of 25 ft (7.6 m) or less (Table 3). Observations of the fishery in 1980 revealed no shift to larger boats. Thus, in comparison to the rest of Bristol Bay, Togiak demonstrates a degree of stability in its fleet with a slight, upward trend in effort.

The commercial fishery is relatively new in Togiak Bay, having begun in the early 1950's. The annual commercial harvest in Togiak Bay has averaged 204,000 sockeye salmon with range limits of 50,000 and 500,000 (ADF&G, Annual Management Report, Bristol Bay area 1966-1976; Preliminary Review of the Bristol Bay Fishery, 1977-1979) and it has accounted for an average of 89% of the annual Togiak District sockeye salmon catch. The yearly exploitation has averaged 55% ranging from 36 to 74%. A minimum mesh size of 13.6 cm (5-3/8 in) is set for use in Togiak Bay until 9 a.m. 20 July of each year. The minimum size is commonly used and is referred to as "sockeye gear". A larger mesh 17.2 to 20.3 cm (6-3/4 to 8 in) is commonly used during the migration of chinook salmon *(Oncorhynchus tshawytscha)* in June and is referred to as "king gear".

The sockeye salmon run (catch + escapement) to Togiak Bay has averaged 358,000 (range 100,800-965,000) for 1966 to 1980 (Figure 3). Fisheries biologists have managed the system for an escapement goal of 100,000 sockeye salmon since 1974, before which the goal varied yearly from 70,000 to 120,000. Hourly escapement to the major river system is estimated from systematic 10-minute counts made from a tower located on each bank of the Togiak River just below the outflow of Togiak Lake. Counts are obtained 24 hours a day during the migration. Since the counting tower first began operation in 1960 escapement has since averaged 138,000 (range 43,000-462,000). The run being fished is thought to be composed of many races, though an average of 88% (range 75-95%) of the total

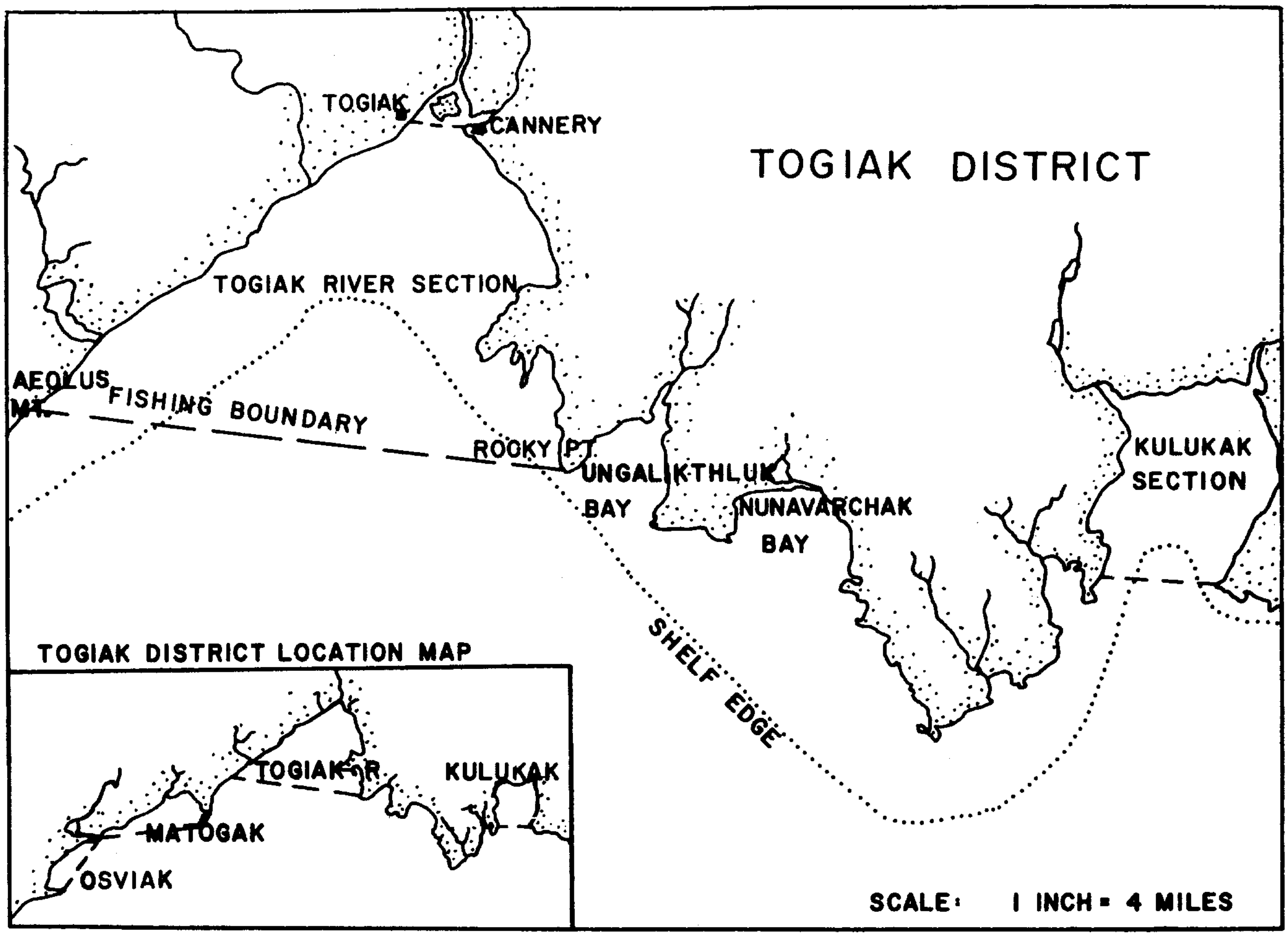


Figure 2. Togiak River section in relation to Togiak District.

Table 2. Effort statistics from the Togiak Bay sockeye salmon fishery.

	Drift gillnet			Set gillnet		
Year	Registered	Max. effort observed thru 7/15	Δ%	Registered	Max. effort observed thru 7/15	Δ%
1967	96	92	0.96	4	1	0.25
1968	100	81	0.81	11	0	0
1969	104	55	0.52	21	0	0
1970	68	[1]		25	[1]	
1971	76	74	0.97	29	3	0.10
1972	81	75	0.92	35	0	0
1973	220	65	0.30	11	1	0.09
1974	111	102	0.92	38	11	0.29
1975	86	75	0.87	21	17	0.81
1976	98	69	0.70	32	14	0.44
1977	97	93	0.95	36	23	0.64
1978	114	101	0.89	32	29	0.90
1979	139[2]	121	0.87	67[3]	41	0.61
1980	139	121	0.87	67	41	0.61

[1]Fish ticket information not available.

[2]Estimated from observed maximum effort and average percent change of 0.87 (1974-1978).

[3]Estimated from observed maximum effort and average percent change of 0.61 (1974-1978).

Table 3. Gear and vessel registration for Togiak District, not including district transfers. Vessel registration does not necessarily equal gear registration.

	Type of gear and allowable fathoms				Vessel registration Keel length (ft)		
Year	Drift	Fathoms	Set	Fathoms	25	26-29	30-32
1967[1]	96	150	4	50			
1968[1]	100	75	11	25			
1969[1]	104	125	21	50			
1970[1]	68	150	25	50			
1971[1]	76	150	29	50			
1972[1]	81	150	35	50			
1973[2]	220	Variable	11	Variable	70	8	1
1974[2]	111	Variable	38	Variable	95	6	4
1975[2]	86	75	21	25	84	6	2
1976[2]	98	150	32	50	101	5	1
1977[2]	97	150	36	50	110	10	3
1978[3]	114	150	32	50	150	12	3
1979[4]		150		50			
1980[4]		150		50			

[1]Based on gear license count at start of season.

[2]Based on gear license count at end of season.

[3]District registration based on the 1973 through 1977 average percentages.

[4]Recent data not yet available.

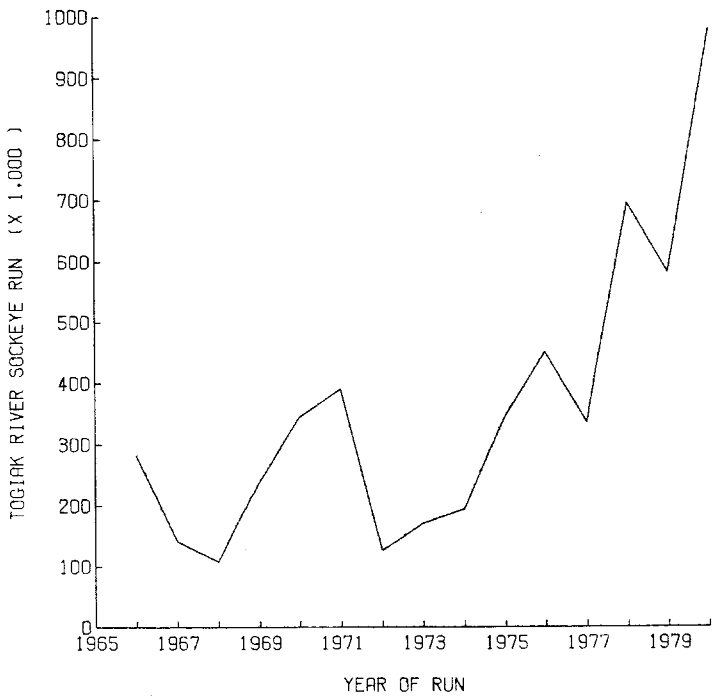


Figure 3. Total run size for Togiak River sockeye salmon, 1966-1980.

run will pass the counting towers (ADF&G, Annual Management Report, Bristol Bay area 1966-1976; Preliminary Review of the Bristol Bay Fishery 1977-1979). Lake Togiak is the major nursery lake, receiving on average 64% of those fish counted by the towers spawning along its shores and tributaries (Nelson 1965, 1966). A portion of the spawners does continue up the Zwischen River (11%) and up into Upper Togiak Lake (17%) (Figure 4). In addition, fisheries biologists make aerial surveys to estimate those which spawn below the towers in the main river channel and the major tributaries to Gechiak, Ongivinuk, and Pungokepuk Lakes (Figure 5). The time necessary for sockeye leaving the bay to pass the counting towers is believed by area biologists to average 10 days. Annual mangement reports give a range of travel time from 7 to 14 days and a tagging study of 1966 found an average travel time of 13.3 days (Pennoyer and Nelson 1967). Since the limited abundance of the run has not until now justified the use of an inshore test fishery, in-season estimates of cumulative escapement are comprised of cumulative tower counts and an estimate of escapement below the towers from aerial surveys.

Thus, the temporal regularity of fishing periods, the apparent relative stability of effort, and the large percentage of the escapement counted daily should accommodate the use of CPUE in estimating daily abundance and total stock while the fishery is in progress.

Objectives

The objectives of the study were as follows:

1) Develop an estimator for daily abundance and escapement from daily CPUE of the Togiak fishery.

2) Develop a migratory time-density function which may more adequately describe the entry pattern than the logistic model used by Royce (1965) and Mundy (1979) as a prologue to total run estimation.

3) Develop a net selectivity coefficient as a function of length for use in describing catchability as a variable.

4) Incorporate the above findings into a management model for Togiak River sockeye salmon which provides a schedule of daily escapement and a total run size estimate during the season.

Fulfillment of the objectives will provide a model particularly applicable to the Togiak Bay sockeye salmon fishery, yet methodology will be useful for other species and systems. Criteria will be developed to evaluate the CPUE of various segments of the fishing fleet with regard to the usefulness in the model. Standards will be provided for definition or isolation of a unit of effort adequate for quantifying CPUE.

It should be stressed that an objective of this research involved the development of a predictive model for Togiak Bay sockeye salmon. This is in contrast to a relational model incorporating the known, true functional relationships between necessary components. Rather, an empirical predictive modeling approach was taken which incorporated the main features of the behavior of

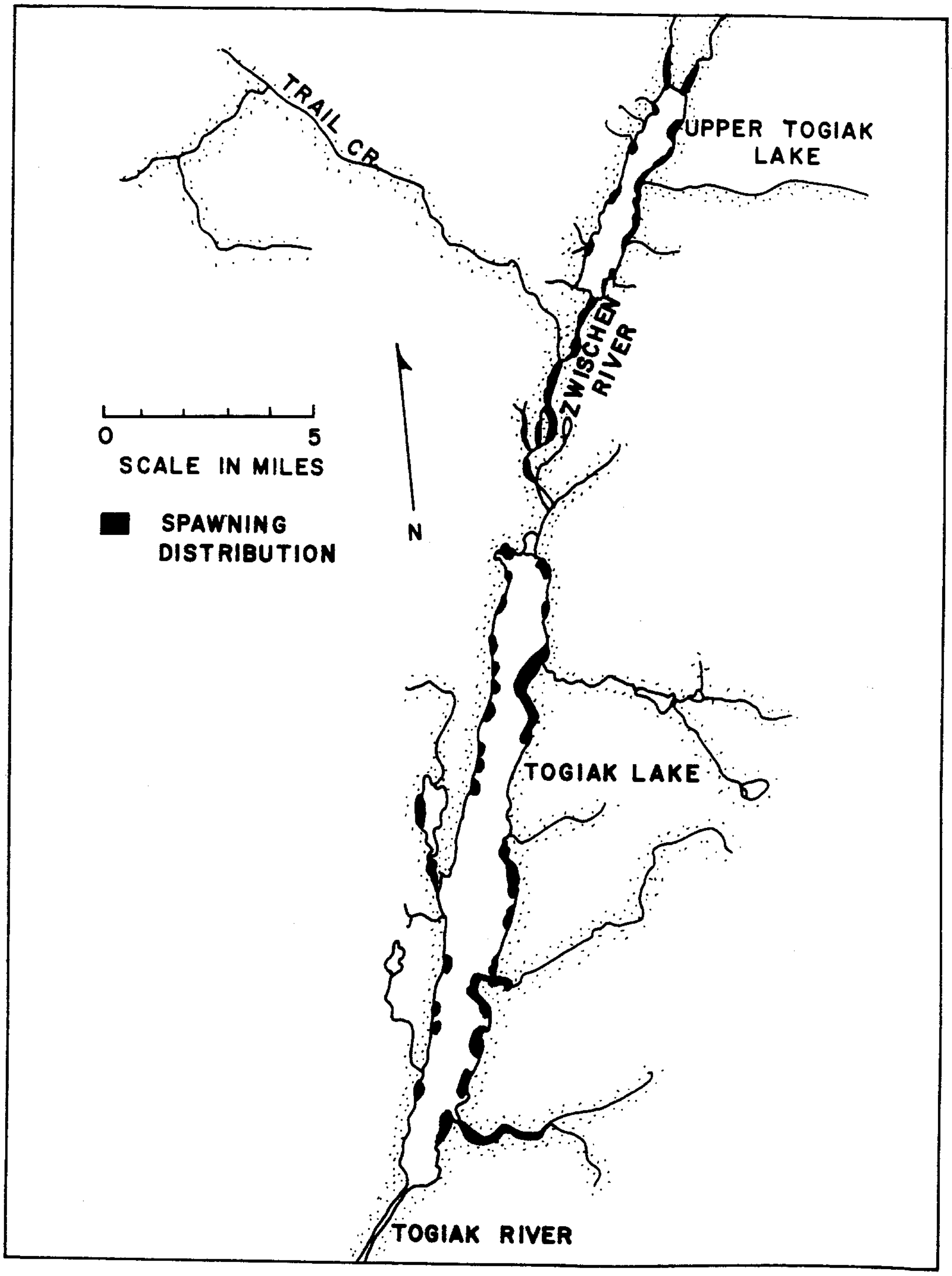


Figure 4. Spawning distribution of sockeye salmon in the Togiak Lakes system (from Nelson 1966).

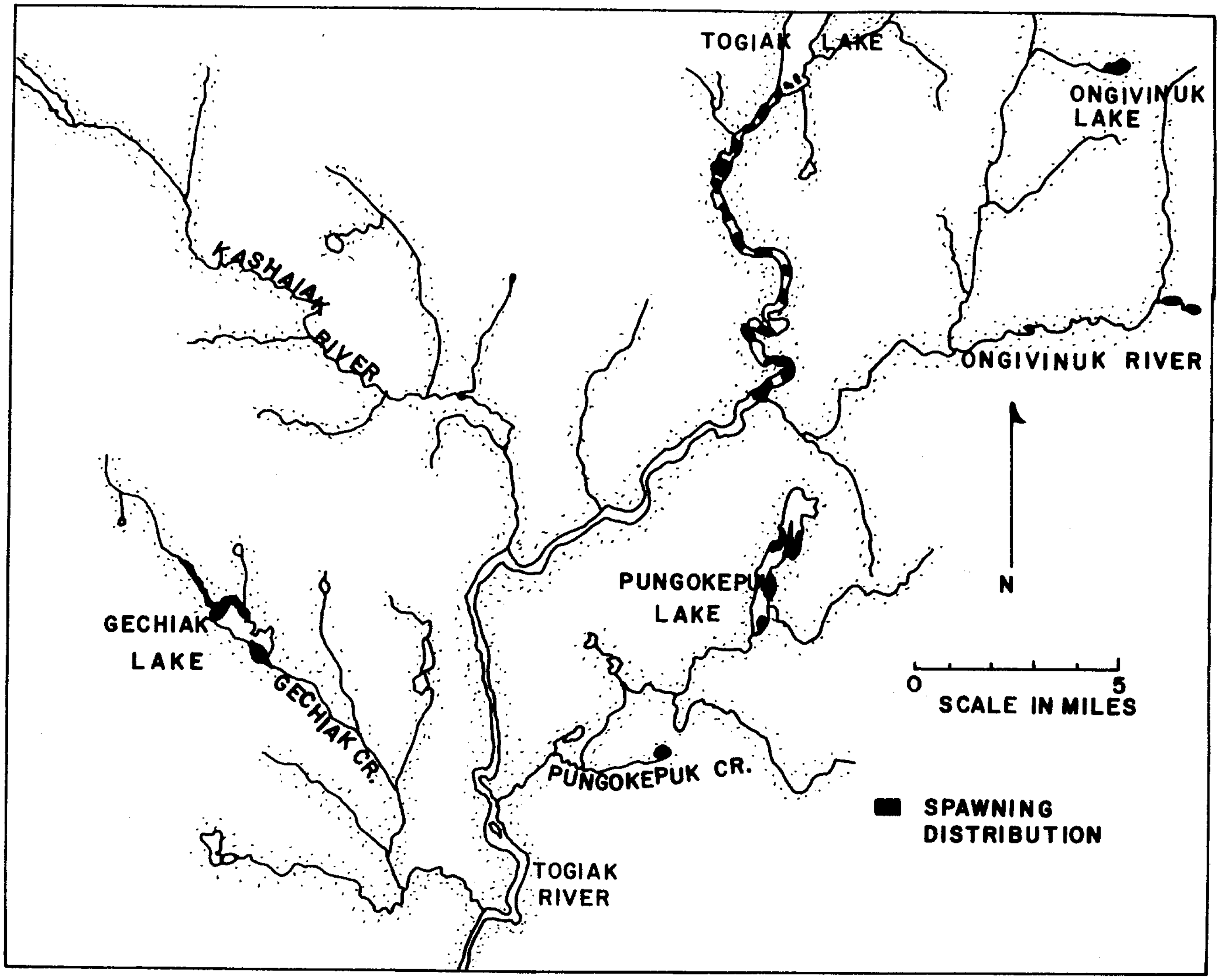


Figure 5. Spawning distribution of sockeye salmon in the Togiak River and tributaries (from Nelson 1966).

the fishery, but which may, in some senses, not presently be verifiable. Assumptions are necessarily made to accommodate available knowledge and data. The utility of the model will depend heavily on the appropriateness of the assumptions and will be judged by its value to the regulatory authorities. In addition, the type of divergence from this goal may identify weaknesses in understanding which require refinement through further research of component relationships, the development of a more complex function, or the inclusion of additional components. The advantage of an empirical or predictive model is that it can be developed prior to complete knowledge of functional relationships and can be tailored to accept readily available data. The predictive model is a predecessor of and not a replacement for the relational model.

PROPOSED MODEL TO ESTIMATE DAILY ABUNDANCE

Theoretical Model

The Togiak Bay sockeye salmon fishery is conducted within a terminal area (Figure 2) in which the salmon are ending their marine migration to enter freshwater. The fish are believed to approach the area from the southeast. Before the present district boundaries were in effect, headland fisheries off Ungalikthluk and Nunavarchak Bays intercepted Togiak River sockeye salmon but have subsequently been closed to fishing (Figure 2). Today the headland fisheries off Rocky Pt. and the next point north are thought to first intercept the incoming run. Togiak Bay is quite shallow, with the inner bay at less than 6 m (19.7 ft) deep at mean lower low water. A shelf separates the inner bay and the outer bay, which drops to 30 m (98 ft). In general the fishermen also believe that the sockeye salmon enter the area from the southeast and cross the bay to the northwest shore following it in towards the mouth of the Togiak River. The shelf edge follows the coastline in this manner cutting over to the northwest shore and the sockeye salmon may be following it to that position rather than the southeast coastline. As found elsewhere in sockeye salmon fisheries with drift gill nets, the catches vary with tidal stage, as does fish movement. The optimal harvest period is the start of the flood, though all tidal stages are fished. Delivery time is limited to a period bracketing high tide because most processors are land-based. In contrast, the set gill nets located at Anchor Pt., near Togiak Village and southeast from the Togiak cannery, make substantial catches on the ebb, indicating that fish move out with the tide along the shore. Drift net boats commonly fish along the shelf and inshore along the northwest coast. Although no studies have yet been conducted to document fish movement, it is believed predictable from observations of the area management biologists and successful fishermen.

In general, salmon fisheries belong to the class designated as "gauntlet" fisheries (Paulik and Greenough 1966). In such fisheries, gear passively lies in wait to intercept fish migrating through the area. A model case occurs in a riverine environment where a restricted migratory route places a spatial difference in gear efficiency, as a different abundance level is available to each unit of gear along this gauntlet. In contrast a competitive fishery is modeled where at any instant equal density is assumed available to all units of effort. This situation is approached by a closed (non-migratory), uniformly distributed marine fish stock. Thus, in a terminal area fishery, aspects of both gauntlet and competitive fishery exist. The salmon are indeed migrating through the area and the degree to which a spatial difference in gear efficiency develops between successive units of effort along their route suggests attributes of the gauntlet. If the sockeye salmon enter in an unknown or diffuse manner, such that the area of high abundance is large enough to accommodate sufficient units of gear to prohibit gauntlet formation, a competitive situation is indicated. Ultimately, the availability of data may dictate the form of the model. A "gauntlet" situation can be modeled only when amount and location of each unit's catch is known along with the route taken by the incoming sockeye salmon.

In Togiak Bay, location of each catch and the precise route of migrating salmon is unknown hence a competitive fishery will be modeled. The daily recruitment is a function of the migratory timing, run strength, and entry pattern. In theory, removals from the area of the fishery are the result of fishing mortality, natural mortality, and continued migration upriver. Natural mortality will be assumed small enough in relation to the others to be considered an insignificant removal in a given day. Historically, catch has been defined as a quantity summed across a unit of time and is represented as the integral of the continuous function:

$$C = F \int_0^1 N(t)\, dt$$

Here, catch (C) is defined as a proportion (F) of the change in abundance $[N(t)\,dt]$ taken over one time period. If daily abundance decreases at a constant rate through a time period, this becomes Baranov's catch equation (Ricker 1975):

$$C_i = qf_i \int_0^1 N_{0i} \exp[-(qf_i+d)t]\, dt$$

$$= \frac{qf_i\, N_{0i}(1-\exp[-(qf_i+d)])}{qf_i+d}$$

where:

C_i = Sockeye catch over unit time period i

f_i = Effort operating during time period i

N_{0i} = Initial abundance present at $t=0$ of time period i

q = Catchability coefficient

d = Rate of departure

Similarly, daily escapement is also a quantity integrated across time which can be represented as:

$$E_i = d \int_0^1 N(t)\, dt$$

$$= d \int_0^1 N_{0i} exp[-(qf_i+d)t]\, dt$$

$$= \frac{d\, N_{0i}(1-exp[-(qf_i+d)])}{qf_i+d}$$

where:

E_i = Escapement of sockeye from the fishing district during unit time period i

It will be assumed that the average stay of fish in the Togiak fishery is 1 day. A large rate of departure (d) is necessary to create a 1-day retention period. Note that the model is asymptotic such that it is necessary to accept an arbitrary error bound defined here as 5%. Thus, given an initial abundance (N_{0i}) at time zero (t_0), only 5% will remain in the fishery at the end of 1 day (N_{1i}) and will be indistinguishable from zero for our purposes. Catch plus escapement then becomes:

$$E_i + C_i = N_{0i}$$

as the large rate of departure dominates the exponential and drives it toward zero. Next, remembering that:

$$C_i = qf_i\overline{N}_i$$

is exact, one can then make a straight line approximation for $\overline{N}_i$ as:

$$\overline{N}_i = \frac{N_{0i}+N_{1i}}{2} = \frac{E_i + C_i}{2} \qquad (1)$$

thus catch becomes:

$$C_i = \frac{qf_i}{2} N_{0i}$$

and when redefining catchability as $q' = q/2$ there remains one unknown to calculate from historical data as:

$$q' = C_i/f_i\, N_{0i}$$

and in-season daily abundance becomes:

$$N_{0i} = C_i/q'f_i$$

resulting in an escapement of:

$$E_i = N_{0i} - C_i$$

In practice the accuracy of the approximation of (1) depends on two factors. Initially, the integrated average has been replaced by a straight line approximation as:

$$\int_0^1 N(t)\ dt/\Delta t \doteq \frac{N_{0i} + N_{1i}}{2}$$

The accuracy of this approximation varies inversely with the length of the interval over which the average is taken: the smaller the interval the better the approximation. Here a 1-day interval was the smallest interval available because of the manner of data collection and is assumed useful.

The second factor involves the validity of the assumption of a retention period of 1 day. If that assumption is violated, the catch equation becomes:

$$C_i = qf_i \frac{(N_{0i} + N_{1i})}{2}$$

where:

$$N_{1i} = N_{0i} \exp\ [-(qf_i + d)]$$

which is now significantly larger than zero. In addition, daily initial abundance (N_{0i}) is the sum of the daily recruitment and those fish left from the previous day. This occurrence affects the definition of catchability, which becomes:

$$q' = \frac{q}{2}[1 + \exp - (qf_i + d)]$$

and is a function of effort. This can be detected if catchability, as derived from historical data, is not constant as previously assumed, but a function of effort. In addition, if the rate of departure is also variable it will decrease the amount of variance accounted for by effort.

There are several additional assumptions involved in the above development. Initially, natural mortality is assumed small enough during one interval of time to be negligible. Recruitment is assumed to be adequately described as instantaneous, or "knife-edge" (Ricker 1975) and incorporated into the initial condition (N_{0i}) for each time period. Lastly, the catchability coefficient is assumed constant as seen by its lack of a time subscript. If found otherwise, catchability must be described adequately as a function to be useful. The validity or the closeness to fulfillment of the above assumptions will be reflected in the usefulness of the model when applied to real data.

Lag Time Analysis

The applied model was developed to estimate daily abundance and escapement during the season and the catchability coefficient was derived from historical data. Though catch information is available daily, the sockeye salmon which escape the fishery are only enumerated later as they pass counting towers (Figure 1), some 48 mi (77 km) up Togiak River (Poe and Mathisen 1981). It is convenient to define daily abundance (N_i) as:

$$N_i = C_i + E_{i+L} \qquad (2)$$

where L is the mean travel time in days for those fish having escaped Togiak Bay on day i is to pass the counting towers.

Travel time is perceived as a constant in that all fish which depart Togiak Bay in a given day will pass the counting towers together within a given day. Yet limited tagging data indicates otherwise, as fish tagged in the mouth of the river on a given day have been observed to pass the towers after 7 to 18 days (Pennoyer and Nelson 1967). Sonar work has also indicated that fish movement is influenced by the tide as fish move inward with the flood. Yet no tidal pulse is observed at the tower, days later, for a smoothing occurs as slower and faster members separate. If there exists a distribution of travel times for a given school of sockeye salmon, constant lag can be viewed as the average lag for an average school. How well this mean fully describes the distribution depends on the dispersal. A large variance or skewed distribution could mask any relationship between CPUE and daily abundance as based on an average lag time. Thus the appropriateness of a constant lag in the predictive model will be reflected in the strength of the relationship between CPUE and daily abundance.

Elsewhere in Alaska where there exists an enumeration of escaping sockeye salmon or the estimation of incoming run strength far removed from the fishery, it has been necessary to develop a lag time between the source of estimation and the fishery. Given such an estimate of travel time, this allows the fisheries biologist to lag escapement estimates back to the time of probable occurrence in the fishing district. When added to that day's catch, it provides an estimate of minimum daily abundance. This minimum estimate ignores fish still present in the bay the next day or the presence of a distribution of travel times.

The lag time value allows one to predict the arrival of the run previously estimated offshore. Several approaches have been taken to estimate the lag time appropriate for a given year and stock. The most rigorous approach has been in the evaluation of abundance estimates from test fish indices. The outside test fisheries off Port Moller in Bristol Bay (Mundy and Mathisen 1981) and Anchor Pt. in Cook Inlet (Waltemyer et al. in press) compare estimates of daily abundance (n_i) from test fish CPUE outside the district with inshore abundance $(\hat{n}_i)$ represented by catch plus escapement. These are initially assumed to be the same population such that they minimize the difference as min. $[\Sigma\ (n_i - \hat{n}_{i+L})^2]$ by varying the lag time (L). Similarly, the inside test fisheries of Bristol Bay are estimating sockeye salmon escapement into major river systems where counting towers are far enough upstream to lessen their effectiveness for in-season management. The test fisheries are considered to sample with replacement in that the removal is so small in relation to the total, one can assume the counting towers enumerate the same population. Again a lag time is necessary to evaluate the escapement estimates from test fish indices, or to modify return per index $(1/q)$ according to the incoming tower counts. In one instance (Meacham 1980), a logistic curve was fit to estimates of escapement from the test fishery $(\hat{e})$ and another to the tower counts $(\hat{E})$. The lag time was then varied to calculate the minimum of $[\Sigma(\hat{e}_i - \hat{E}_{i+L})^2]$ with the choice of lag time being that which minimized the above relationship but was still consistent with biological data from tagging studies and other research. At another site, correlation analysis was conducted on the cumulative test fish index curve with the tower counts a given number of days later. Choice of a lag time (McBride 1980) was that which produced the largest coefficient of determination (R^2). One attempt to match catch and escapement curves was performed by Royce (1965) with Bristol Bay data. Royce fit the logistic curve to historical catch and escapement data, resulting in two average curves for each system. The average number of days from estuary to tower (an average lag time) was then derived as the difference in time of the subsequent peaks of these curves. This approach did not minimize curve differences of varying lag times as average curves were compared only at one point. This resulted in an average lag time of 11 days for Togiak River sockeye salmon based on data from 1960 to 1964.

These techniques for estimating lag time were presented to illustrate that most previous work has involved the comparison of attributes of an unaltered population at two points in space. Whether the attribute is escapement or daily abundance, the act of sampling has presumably not altered the population. In terms of gear selectivity by gill nets in relation to fish size, the estimate has been adjusted in the test fisheries (Yuen 1980). In contrast, the lag time necessary to reconstruct the entry pattern of daily abundance [in formula (2) above] is more involved. Though catch and escapement may follow a similar trend, they are not estimating the same population. The mere act of removal by the commercial fishery, which is a function of allocated fishing time and available effort, has substantially altered the population which is left as escapement. Thus a minimization process to compare the two curves does not necessarily result in the best estimate of lag time. The curves are not two estimates of the same quantity but rather are complementary with the sum being the entry pattern of interest.

Plots of catch and escapement curves of data from 1967 to 1980 indicate that lag time has varied substantially. Thus, in Togiak, it was hypothesized that lag time differed enough between years such that an average travel time (Royce 1965) would not be useful. As the catchability coefficient was to be estimated with the greatest precision, lag time was allowed to vary yearly. Catchability is assumed to be constant in the theoretical model, but as previously stated, it may vary. One such variance component could be an inadequate choice of lag time, for in data which are collected in a time series, a relationship could be developed as:

$$q = C_i/(C_i+E_{i+L+1})f_i \text{ or } q = C_i/(c_i+E_{i+L-1})f_i$$

Yet this incorporates the additional condition that E_{i+L} is proportional to $E_{i+L\pm 1}$. In calculating catchability with a range of escapements $(\ldots, E_{L-1}, E_L, E_{L+1}, \ldots)$ any choice other than the true lag time incorporates this assumption. On the other hand, if the constant of proportionality varies daily, one has added an unnecessary variance component due to the poor choice of lag time. Thus a relationship could be developed and tested over a range of lag times where it is maintained that the best estimate of lag time of a given year is that which minimizes the variance in the catchability coefficient. This more closely fulfills the assumptions of the model. Yet catch and escapement curves hold valuable information that should not be discarded. As previously argued, these curves should not be used in a minimization process, although graphical analysis much like that of Royce (1965) could be done to match the curves at a given percentage level.

Criteria were developed for the calculation and choice of a lag time between the bay fishery and the counting towers at the Togiak Lake outflow. The primary criterion for lag time selection was the reconstruction of the "best" entry pattern possible [as in formula (2)] using a finite lag. The estimate also must agree with available tagging data and behavior information on plausible swimming speed. Though it could vary yearly, it must agree with the graphical analysis of cumulative proportion curves of catch and escapement. The choice should ultimately minimize the variance in catchability which most closely fulfills that model assumption.

The catchability coefficient was calculated for a given day and year as:

$$q_i = C_i/(C_i+E_{i+L})f_i$$

where the lag time (L) was varied over a biologically plausible range and the variance of catchability was calculated for each lag. The actual choice of a lag time was based on the minimum coefficient of variation (CV) for the catchability coefficient which is the standard deviation (SD) divided by the mean $(\bar{q})$. This relative measure of dispersal facilitates the comparison among variances based on means of differing magnitude. Table 4 presents the statistics developed for various lags using data from 1967 through 1980 for effort of all gear types. The last day of the tower counts of a given year was not included as counting ends at 6 a.m., resulting in an estimate of daily abundance which is too low. The data were also truncated in that days before 4% of the run is accounted for were not included. This period yields highly variable estimates of catchability, disproportionately increasing the variance because of the low number of fish caught incidental to the chinook salmon fishery. Data were also truncated in years of price disputes (1975 and 1980) when data prior to the settlement were not included, again, because of the catches being incidental to the chinook salmon fishery. The resulting lag times which minimized the coefficient of variation ranged from 7 days in 1978 to 14 days in 1976 (Table 4).

The graphical analysis of cumulative proportion curves consisted of comparing them at the 10% level where the difference in time became an estimate of the lag time. It was judged that at this point they were still quite parallel. Catch was accumulated until the tower was closed. Understandably, catch data

Table 4. Statistics for the catchability coefficient (q) developed under various lag times.

Year	Lag time, days	n	$\bar{q} \times 10^{-2}$	SD $\times 10^{-3}$	Coefficient of variation (CV) of q	Lag time minimum CV, days
1967	8	13	1.21	7.70	0.636	
	9	12	1.16	8.50	0.733	
	10	12	0.97	3.34	0.345	10
	11	12	1.01	4.22	0.418	
	12	12	1.09	4.77	0.410	
	13	13	1.08	5.88	0.544	
1968	8	23	1.32	6.60	0.500	
	9	23	1.36	9.54	0.701	
	10	23	1.38	7.20	0.522	
	11	23	1.35	5.39	0.399	11
	12	23	1.56	10.02	0.642	
	13	24	1.42	6.91	0.487	
	14	24	1.44	9.42	0.654	
	15	23	1.49	12.38	0.831	
1969	8	8	1.72	11.54	0.671	
	9	7	1.43	6.22	0.435	
	10	8	1.55	6.62	0.427	
	11	9	1.65	6.41	0.388	11
	12	9	1.65	8.49	0.514	
	13	10	1.53	11.34	0.741	
	14	10	1.33	9.59	0.721	
1971 [1]	8	27	1.28	5.44	0.425	
	9	27	1.33	6.20	0.466	
	10	27	1.45	9.78	0.674	
	11	27	1.27	6.13	0.483	11 [2]
	12	27	1.52	10.69	0.703	
	13	28	1.52	12.36	0.813	
	14	27	1.51	10.41	0.609	
1972	11	6	2.19	25.96	1.186	
	12	6	1.14	2.62	0.230	
	13	6	1.15	2.39	0.208	13
	14	6	1.40	9.28	0.663	
	15	7	0.99	3.64	0.368	
	16	7	0.78	3.29	0.422	
	17	8	0.76	3.67	0.482	
1973	11	13	1.34	6.39	0.478	
	12	12	1.36	11.48	0.844	
	13	12	0.99	4.70	0.474	13
	14	11	0.92	5.15	0.559	
	15	10	0.86	5.24	0.609	
1974	8	12	1.02	3.61	0.354	
	9	12	1.01	3.86	0.384	
	10	12	1.10	8.26	0.751	
	11	12	0.87	2.89	0.332	11
	12	12	0.95	3.90	0.411	
	13	13	0.88	4.26	0.484	
1975	6	18	1.00	5.02	0.502	
	7	17	0.94	3.82	0.406	
	8	17	0.99	3.66	0.370	
	9	16	0.96	2.72	0.284	
	10	15	1.05	2.96	0.282	10
	11	14	1.14	3.24	0.285	
	12	13	1.26	3.74	0.297	
1976	11	19	1.20	4.98	0.415	
	12	18	1.19	4.33	0.364	
	13	18	1.22	3.94	0.323	
	14	17	1.19	3.58	0.300	14
	15	16	1.25	5.65	0.452	
	16	16	1.15	5.17	0.449	

- Continued -

Table 4. Statistics for the catchability coefficient (q) developed under various lag times (continued).

Year	Lag time, days	n	$\bar{q} \times 10^{-2}$	SD $\times 10^{-3}$	Coefficient of variation (CV) of q	Lag time minimum CV, days
1977	9	21	0.82	2.89	0.353	
	10	20	0.81	2.43	0.296	
	11	19	0.82	2.19	0.267	
	12	18	0.79	1.71	0.216	12
	13	19	0.75	1.96	0.261	
	14	19	0.73	2.23	0.305	
	15	19	0.71	2.47	0.348	
1978	6	28	0.80	3.58	0.448	
	7	27	0.76	2.63	0.344	7
	8	27	0.75	2.79	0.369	
	9	26	0.74	2.55	0.345	
	10	27	0.74	2.81	0.380	
	11	27	0.72	2.87	0.400	
	12	26	0.70	3.15	0.448	
	13	27	0.72	3.53	0.493	
	14	27	0.68	3.12	0.460	
	15	25	0.68	3.59	0.527	
1979	6	26	0.71	2.71	0.381	
	7	26	0.74	3.50	0.474	
	8	25	0.71	2.45	0.344	
	9	24	0.72	2.50	0.345	
	10	23	0.70	1.87	0.268	10
	11	22	0.69	2.02	0.295	
	12	22	0.70	2.71	0.385	
	13	23	0.69	3.19	0.465	
	14	22	0.65	2.97	0.459	
1980	6	22	0.74	4.16	0.560	
	7	20	0.74	4.40	0.593	
	8	19	0.74	4.42	0.596	
	9	18	0.81	5.95	0.733	
	10	17	0.91	7.59	0.831	
	11	16	0.79	3.77	0.477	11
	12	15	0.80	4.04	0.506	
	13	14	0.91	5.74	0.630	
	14	13	0.87	4.82	0.554	

where: $\bar{q}$ = mean catchability
CV = coefficient of variation
SD = standard deviation of catchability
n = sample size

[1] Data not available for 1970.

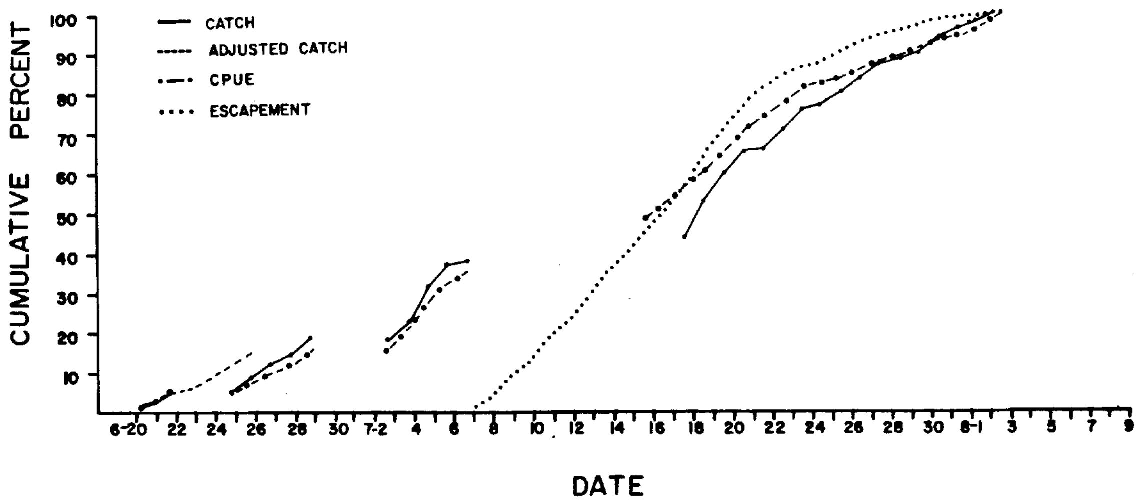
[2] Lag time chosen with minimum CV which was also compatible with graphical analysis.

could have been truncated prior to the tower closure based on the mean lag time of Royce (1965), but that would have presupposed a lag time *a priori* to curve matching. When data were truncated *a posteriori* with the average estimate of lag time, the time difference between the curves at the 10% level changed by much less than 1 day. Some adjustment was also made for closed periods creating a range for lag times from curve matching. For example, suppose the 10% level of the catch curve on 1 July followed a week-end closure of the fishery. Such considerations create a range for the 10% level of 29 June to 1 July, resulting in a similar range in lag times. The catch per boat (CPUE) cumulative proportion curve was also analyzed, and it was found to agree closely with the catch curve.

Two circumstances made the curve matching of catch and escapement useful only in a qualitative manner. First, in years of low harvest, extended closures were enacted which sufficiently altered the shape of the catch curve, degrading its usefulness (Figure 6). These closures often occurred in mid-season, which further substantiated the choice of matching at the 10% level rather than at the 50% level. Secondly, in years of price disputes, curtailed fishing early in the season allowed a large number of fish to escape. Consequently, the 10% level is reached sooner for escapement and later for the catch than under the normal fishing pattern, negating the usefulness of this match. This can be seen in 1975 and 1980 (Figure 7). The CPUE curve in this case differs substantially from the catch. The CPUE from the low effort early in the season better reflects the entry pattern than the catch since CPUE is independent of the amount of effort, although both catch and CPUE at this time are most likely incidental to the chinook salmon fishery. Thus the CPUE curve was matched with the escapement curve at the 10% level in years of price disputes. Finally, only in years without extended closures or price disputes (Figure 8) can one see that the curves parallel to the 10% level and how the adjusted catch curve at the 10% level creates a range of lag times. Appendix A presents the catch and escapement cumulative proportion curves that are not specifically discussed in the text below.

Lag times were thus developed under varying criteria (Table 5) for the years 1967 to 1980. Because of the close agreement of lag times derived from variance minimization and curve matching, the lag times from the minimization process will be used in all subsequent analysis. The historic average lag time was 11 days which matches that found by Royce (1965). All lag times are in agreement with the range of 7 to 13 days described by ADF&G fisheries biologists in annual management reports and 6 to 14 days with an average of 10 days as found from tagging for travel time in Togiak River (Pennoyer and Nelson 1967).

With lag time chosen, the yearly entry pattern for 1967 to 1980 has been established. The sockeye salmon run to Togiak River and that being harvested in Togiak Bay has been defined by the duration of the tower counts and truncation of data as described earlier. Daily abundance will only be defined for periods in which escapement estimates are available. Catches of sockeye salmon made outside such time periods will be assumed not bound for Togiak Lake when using a mean lag time. Thus, the sockeye salmon run begins for purposes of estimating daily abundance and escapement when 4% of total abundance is accounted for and lasts until L days before closure of the tower, where L is the lag for that year (Table 6).



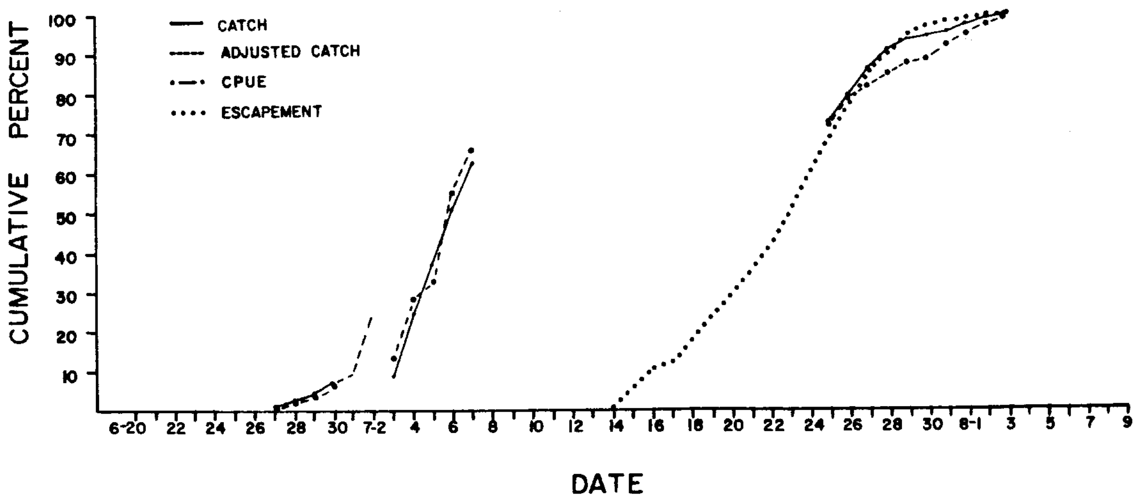
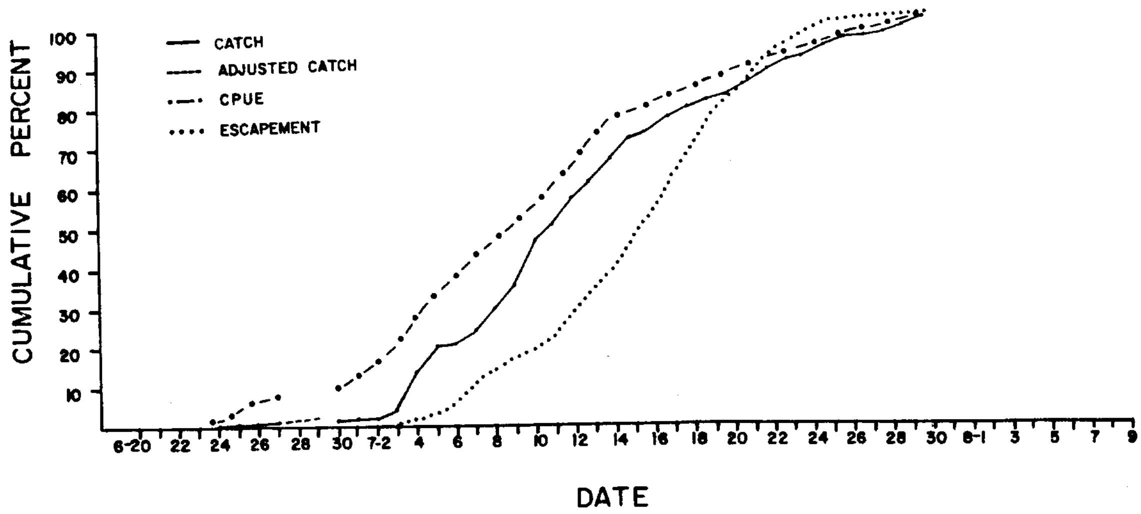


Figure 6. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery: top - 1973; bottom - 1974.



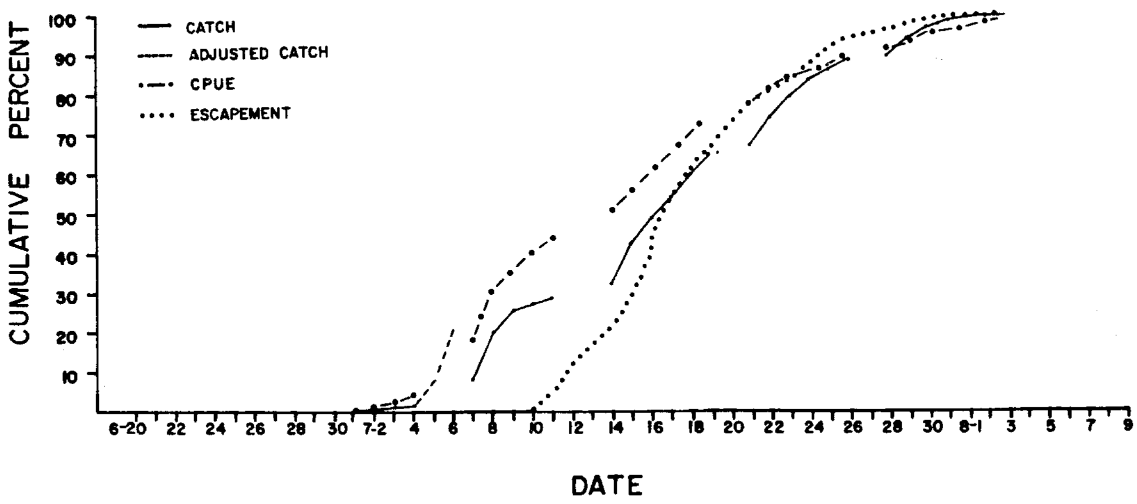


Figure 7. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery: top - 1980; bottom - 1975.

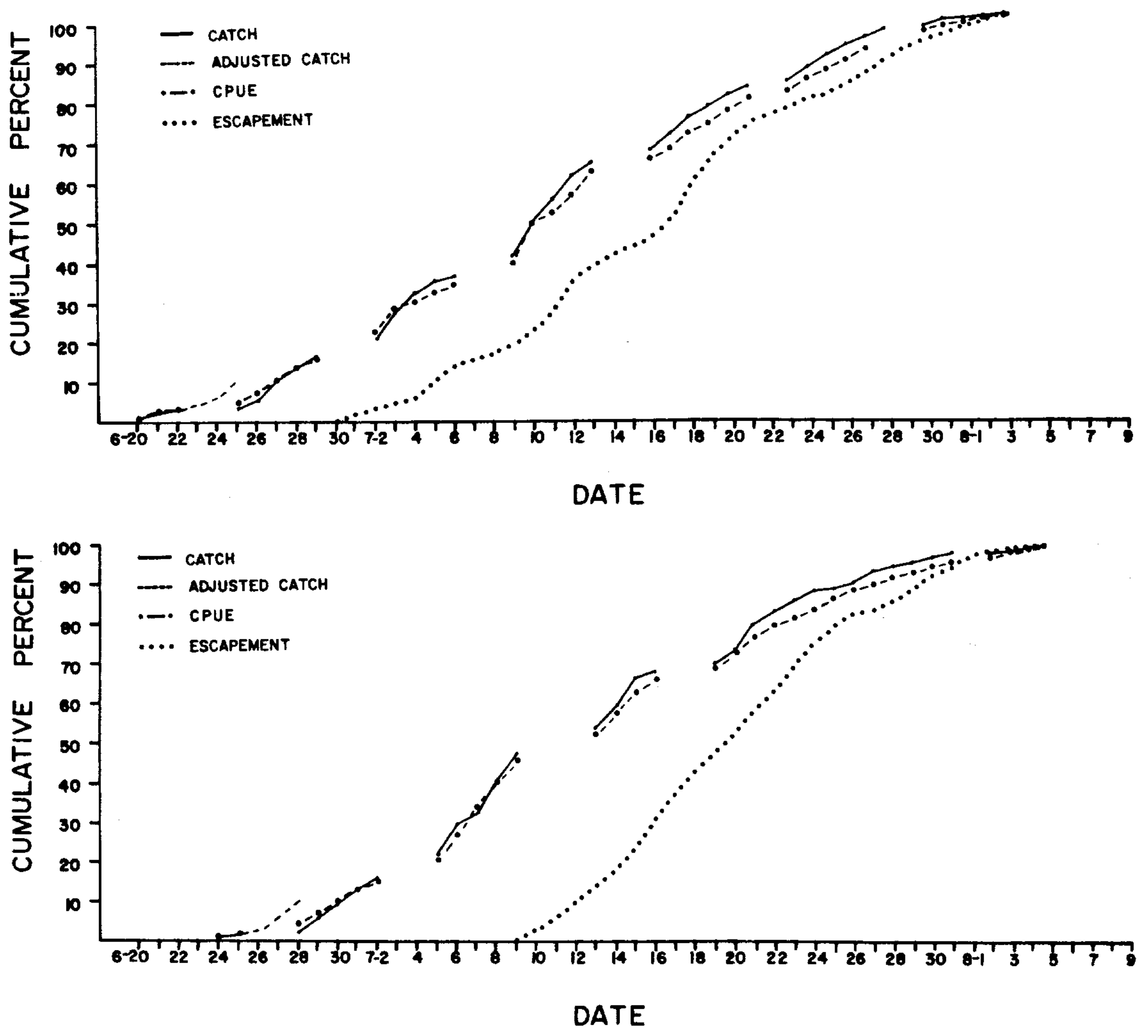


Figure 8. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery: top - 1979; bottom - 1976.

Table 5. Lag time in days between fishery and counting tower obtained under various criteria, 1967-1980.

Year	Matching cumulative curves of proportions for catch and escapement		Minimum variance of catchability using the following lag time
	At 10%	At 10% adjusted for closed periods	
1967	10	12	10
1968	10	12	11
1969	10	12	11
1971[1]	11	13	11
1972	13	15	13
1973	13	15	13
1974	9	11	11
1975[2]	7	9	10
1976	12	14	14
1977	10	12	12
1978	5	7	7
1979	8	10	10
1980[2]	7	9	11

[1] Data not available for 1970.

[2] In years of price disputes, curves of cumulative proportions of catch and CPUE differed substantially. The CPUE curve was used.

Table 6. Timing and duration of the Togiak River sockeye salmon run for 1967-1980.

Year	Lag time	Day 1	50%	End	Duration (days)
1967	10	6/26	7/07	7/24	29
1968	11	6/23	7/04	8/05	44
1969	11	6/26	7/06	8/03	39
1971[1]	11	7/03	7/14	8/07	34
1972	13	6/30	7/07	7/21	22
1973	13	6/25	7/05	7/23	29
1974	11	6/23	7/02	7/23	31
1975	10	7/01	7/10	7/25	25
1976	14	6/27	7/08	7/22	26
1977	12	6/25	7/05	7/23	29
1978	7	6/25	7/07	7/28	34
1979	10	6/24	7/09	7/24	31
1980	11	6/25	7/07	7/19	25

[1]Data not available for 1970.

Choice of a Unit of Effort

Having reconstructed the historical entry pattern, actual computation of the catchability coefficient follows development of a unit of effort. Choice is contingent on the data being available historically and in-season, while most closely fulfilling the assumptions of the model. During the season, a receipt of sale is written for each landing in the fishery on which is documented: date of sale; the license holder's name, number, and gear type; statistical area of catch; and the catch by species in numbers and pounds. Ultimately, these receipts, called fish tickets, are computer-processed, allowing the fisheries biologists to request catch statistics summaries. In Togiak, the regular fishing period runs from 9 a.m. Monday to 9 a.m. Friday, and catch has been allocated to five calendar dates where only four 24-hour periods were fished. Still, the unit of effort will span a 1-day period, remembering the straight line approximation made in model development which dictates choice of the smallest time period for which data are available.

Two types of gear are used in the Togiak District, drift gill nets and set gill nets. Daily statistics have been compiled by boat, referring to the ADF&G number of the license holder and by landing, referring to the actual sale resulting in the production of a fish ticket. The difference arises as a given license holder may sell fish more than once per day so that the number of boats is always less than or equal to the number of landings but it is assumed that fishermen do not hold fish for more than 1 day before delivering. This allows two effort schemes for each gear type where boats per day represents the number of different license holders delivering catch in a given day. In contrast, the number of landings per day is the total number of deliveries in a given day represented by the number of fish tickets. There are also three modes of analysis: by drift gill nets, by set gill nets, or pooled gear types. Thus, for historical analysis there are six possible units of daily effort resulting from three gear types (drift, set, and both) and two counting schemes (boats and landings). Within-season catch and effort data are reported daily by shortwave radio to the area management biologist. In the past, processors summed catch by day and counted the number of deliveries. Thus, effort within the season is collected as landings per day of all gear types.

In theory it is desirable to define a unit of effort so that daily CPUE is proportional to daily abundance; the necessary data are available during the season, and the effort measure is proportional to the rate of fishing (F). Ideally, units of effort should be strictly additive so that an increase in effort (f) results in linear increase in fishing mortality (F) as $F=qf$. Once again, the necessity of a constant coefficient of catchability (q) is demonstrated. A unit of effort should also be comparable between years so that a relationship for catchability (q) can be developed from historical data. A contant vessel efficiency or fishing power must be assumed. The fishing power is affected by such factors as actual time spent fishing and the gear type, dimension, and efficiency. Many vessel characteristics are also involved (Blondal 1975) such as dimension, engine horsepower, number of crew, vessel tonnage, and qualitative factors such as crew ability or instrumentation. Gear competition or actual physical interference between units also affects efficiency.

Therefore, to most closely fulfill ideal conditions, while allowing use of available data, a day's fishing was used as the time unit. Even though not a precise measure for actual fishing time, this allows the expression of effort for the different gear types in comparable units (Dunin-Kwinta 1975). To stabilize gear dimension, only data from 1976 to 1980 were used as a sliding gear regulation was in effect from 1973 through 1975 (Table 3). Data available prior to 1973 (1967 through 1972) was also not used so as to minimize the time during which gear efficiency and vessel factors could have changed.

Evaluation began with the six different units of effort; all gear types, drift nets, and set nets each as boats or landings per day. Criteria for subsequent use in further analysis could be based on its homogeneity, availability, and resulting calculation of a constant catchability coefficient. Thus, only data from years with comparable fishing power was used. As seen in Table 3, no major trend to the use of larger boats has occurred in Togiak since compilation of keel length statistics began in 1973. Also, maximum gear length was constant after 1976. No information on vessel factors is available, although based on observational knowledge of the fishery, it has been relatively stable. There has been no dramatic introduction of sophisticated electronic or hydraulic equipment in the last few years. Lastly, a workable relationship for catchability is desirable. A unit of effort can be chosen to give the least variation in CPUE of homogeneous vessels (Poinsard and LeGuen 1975). Taken a step further, a unit of effort should also take a constant proportion of the stock where the constant of proportionality is the catchability coefficient. Thus, a unit of effort was chosen to minimize the variance of catchability.

Catchability was calculated from comparable years 1976-1980, using the same within-year data span as in the lag time analysis. The resulting relationship was:

$$q_{ij} = C_{ij}/f_{ij}(E_{i+L}+C_{ij})$$

where the catchability coefficient (q_{ij}) was related to effort (f_{ij}) of gear type j along with the resulting day's (i) catch (C_{ij}) and escapement (E_{i+L}) using the yearly lag time L. Table 7 summarizes the results of the analysis for all units of effort. The actual value for yearly mean catchability and its variance are not comparable between gear types as they are not estimates of the same quantity. However, the coefficient of variation (CV) which expresses sample variability in relation to the mean is comparable. Greatest variability is seen in set nets which may be due in part to their sensitivity to weather, tidal stage, and changes in fish distribution. Also, general sampling variability may be the cause as effort was low in this category. Thus, the use of boats per day for all gear types minimizes the variance of catchability fulfilling that requirement. Yet, that unit of effort is not readily available within the season as a license holder may sell more than once a day to a given processor which could be detected only if the reporting system were altered. However, if a fisherman sells to more than one processor in a given day, this would not be detected until the fish tickets from all processors have been received by the area management biologist. In contrast, the unit most readily available in-season is the number of landings from all gear types. Note that it is but the second best variable and its CV differs from that of boats by less than 5% in four of the 5 years and less than 10% for all years analyzed (Table 7).

Table 7. Catchability statistics for various units of effort.

Year		All gear		Drift gillnets		Set gillnets	
		Boats	Landings	Boats	Landings	Boats	Landings
1976	$\bar{q} \times 10^{-2}$	1.19	1.04	1.36	1.20	2.47	1.47
	SD $\times 10^{-3}$	3.58	3.32	4.25	3.85	19.80	9.11
	CV	0.30	0.32	0.31	0.32	0.80	0.64
1977	$\bar{q} \times 10^{-2}$	0.79	0.65	0.96	0.81	1.34	1.03
	SD $\times 10^{-3}$	1.71	1.95	2.34	2.56	6.41	5.24
	CV	0.22	0.30	0.24	0.32	0.48	0.51
1978	$\bar{q} \times 10^{-2}$	0.76	0.65	0.929	0.81	1.42	1.16
	SD $\times 10^{-3}$	2.63	2.53	3.61	3.46	9.07	7.58
	CV	0.34	0.39	0.39	0.43	0.64	0.65
1979	$\bar{q} \times 10^{-2}$	0.70	0.60	0.93	0.81	1.13	0.92
	SD $\times 10^{-3}$	1.87	1.89	3.12	3.05	5.28	4.79
	CV	0.27	0.32	0.33	0.38	0.47	0.52
1980	$\bar{q} \times 10^{-2}$	0.79	0.67	1.03	0.92	1.22	0.93
	SD $\times 10^{-3}$	3.77	3.22	5.76	5.54	10.50	6.66
	CV	0.48	0.48	0.56	0.60	0.86	0.72
$\overline{CV}$		0.32	0.36	0.37	0.41	0.64	0.60

where: $\bar{q}$ = mean catchability.
SD = standard deviation.
CV = coefficient of variation.
$\overline{CV}$ = mean CV

Subsequent analysis was based on those two units of effort to detect any substantial difference in their precision. Landings are more readily available during the season and should be used. However, if a substantial improvement were demonstrated in the use of boats, it could be maintained as a back-up scheme with an additional lag of 1 week for fish tickets to be received in the ADF&G office.

Several assumptions and restrictions are contained in this choice of a unit of effort. By grouping gear types, an average unit has been created and as long as the proportion of set-to-drift nets remains stable (Table 8), the within-season CPUE will be comparable to historic data. The usefulness of the average may also vary with the number on which it is based and data may be rejected if effort falls below some critical level. As pointed out above, any drastic change in fishing power or vessel efficiency will degrade its usefulness.

Investigation of Variance Components of Catchability

The analysis of catch and effort data has, until now, been based on a general assumption that the portion of the population caught is proportional to the effort put into the process of capture. One unit of effort is assumed to catch a fixed proportion of the population. The fishery is viewed as a Poisson sampling process in which the probability of an individual being captured is proportional to the number of units of gear fishing (Seber 1973). Thus, all units of effort are assumed to be operating independently with no physical interference or competition and all fish are assumed to have the same probability of capture. As described earlier in the model derivation, effort was summed across a 1-day period. The catch (C_i) from this effort (f_i) of day i was then modeled as:

$$C_i = qf_iN_i$$

The absence of a time subscript for the catchability (q) coefficient emphasizes the assumption of consistency in the proportion of daily abundance (N_i) a level of effort will remove as catch (Paloheimo and Dickie 1964). Yet, as seen earlier, in our choice of lag time and unit of effort, catchability did vary and its minimization was a criterion for their choice.

In practice, any estimate of catchability will incorporate the cumulative interaction of such variables as the following: (1) fishing power of a vessel; (2) gear type and dimension; (3) vulnerability of a fish population to a particular ground; (4) aggregation of fishing units on the fishing ground; and (5) physical phenomena, such as weather and tides.

The likelihood of catchability being constant for all individuals across time will depend in part on the presence and interaction of these factors. The influence of each of these variables was evaluated in terms of minimizing the variance of the daily catchability coefficient as calculated from historical data.

Initially, only data since 1976 were used to minimize the effect of changes in fishing power. This eliminated any effect of a long-term trend in fishing

Table 8. Mean proportion of total daily effort for set and drift nets by landing and by boat.

	Proportion of total effort			
	Boats		Landings	
Year	Drift gillnet	Set gillnet	Drift gillnet	Set gillnet
1976	0.859	0.145	0.846	0.154
1977	0.811	0.197	0.789	0.211
1978	0.787	0.213	0.778	0.222
1979	0.724	0.276	0.712	0.288
1980	0.742	0.258	0.720	0.280

power or efficiency as was addressed in the discussion on choice of a unit of effort. The effect of differing gear types was also addressed in the choice of effort in that if the proportion of drift to set nets remains fairly constant (Table 8), the variance of catchability was minimized in the choice of a pooled gear type. In addition, data were truncated to include only that portion of the run after 4% was accounted for, minimizing the inclusion of data involving sockeye salmon captured by "king gear" as defined in the introduction. Mesh size is not indicated on the delivery ticket and it is assumed that "king gear" was not used past 1 July. Even with the sole use of "sockeye gear", the test fisheries of Bristol Bay (Meacham 1980) have again shown just how sensitive catchability is to differing average fish size (Baranov 1948; Hamley 1975). Thus, for Togiak, some notion of selectivity of gill nets and its interaction with the variation in average fish size is indicated.

The aggregation of fishing units on the sockeye salmon population may affect catchability if competition or physical interference develops between units of effort affecting the efficiency of each. In addition, the sockeye salmon may be entering the district in a restricted but predictable manner and fishermen may regulate fishing effort in proportion to density present. Thus, favored fishing areas of dependable catchability develop and if they are size-limiting, an increase in effort may force some fishermen to fish areas of lower or unpredictable density. The result is that a linear increase in effort would not be accompanied by a linear increase in catch (under constant initial abundance) thereby, causing catchability to vary. Varying levels of effort could affect catchability indirectly as it affects overall soaking time, gear efficiency, or placement. Lastly, recalling the model derivation, if the retention period is greater than 1 day, catchability will vary with effort (see p. 15). These occurrences were investigated to determine if a relationship could be developed between the level of effort and catchability.

Physical phenomena may also affect catchability. Weather can cause the fleet to be less effective, e.g., high winds and wave action will increase the dropout rate and even alter fishing time within a day. As daily weather data for Togiak were unavailable, a portion of the unexplained variance of catchability can be attributed to changes in weather. In addition, salmon movement in an estuarine environment varies with tidal stage, and as gill nets are a passive gear dependent on this movement, catches will vary likewise. Access to some buying stations is limited to a few hours bracketing high tide. Land-based processors normally begin to receive deliveries 2 hours before high tide. Historical daily CPUE estimates can be theorized equivalent in representing daily abundance only if they all incorporate similar patterns of tidal stages necessary for optimal fishing and delivering. For example, given equal daily abundance, CPUE estimates of 2 days could differ widely if one 24-hour period included only one optimal fishing (or delivery) tide while the other included two. Tide data are available and a relationship was tested to relate catchability to daily tidal cycle.

Here the goal was to quantify as much variation in catchability within and between years so as to estimate daily abundance. Only data since 1976 were used as described earlier. Days with effort less than 20 were deleted. Especially evident was low effort on Sundays when fleet composition is markedly altered because of the religious affiliation of the fishermen. Analysis used catch and effort from all gear types, boats, and landings.

It was postulated that a large portion of the observed variance in catchability could be explained through the use of an appropriate model incorporating variables which could contribute to such variance. The criteria for including a variable was that it be possible to obtain the necessary information within the season. Thus, such items as total run size, daily abundance, and averages of developed variables would not be used. Seven variables were defined (Table 9). The first was daily effort in landings or boats of all gear types, used to determine if a relationship with effort could be found. Day of the run was used to detect an association of catchability with time within the season. Day one was then defined as the probable occurrence of 4% of the cumulative run. Thus, the initial time is not a serial date, but linked to the timing of the sockeye salmon run which incorporates its reaction to environmental factors. In addition, catchability could vary with time in response to several occurrences which are less readily quantified. First, there may be a learning factor affecting effort efficiency through a given season as fishermen test or break in new gear, crew members, and techniques as the sockeye salmon run begins. Secondly, "king gear" (as defined in the introduction) may still be fished early in the season, its use being affected by the presence of substantial numbers of sockeye or chinook salmon. In addition, the transition of the fleet from "king" to "sockeye gear" may take several days. Next, it is assumed that the observed entry pattern is conserved across generations as found in Bristol Bay and elsewhere (Thompson 1951; Vaughan 1954). Relative abundance then becomes a function of day of the run, resulting in a proportion of total run expected by day. Thus, in Togiak where processor limitations have been documented during the second week of the run (1976, 1978-80), this becomes related to days of the run where large abundance occurs. Daily abundance is not permissable as a variable, being an estimated quantity, while day of the run is, and the days of processor limitations where catchability is artificially lowered through limits or cessation of buying can be detected. It has also been observed from aerial survey data (ADF&G, Annual Management Report, Bristol Bay area 1966-1976) that, on the average, 12% of the run is bound for the tributaries or spawns in the main river channel and is not counted by the towers. Substantial catches are also observed late in the season when tower counts have declined considerably and continue after the tower closes. It thus seems plausible that these fish are late-timed runs bound for the main river and lower tributaries and their escapement is not incorporated into the daily abundance of historical data. It is postulated that catchability varies with the influence of these runs late in the season and can again be detected by day of the run. It is assumed that the first day of the run can be detected within the season without error and thus is not an estimated quantity.

A tide index was also developed to evaluate the consistency and influence of a day's tidal pattern on catchability. At the major land-based processor in Togiak, deliveries of catch normally begin two hours before the high tide. Depending on such things as amount of effort, CPUE, and quantity of off-loading cranes operating, delivery may last up to four hours past high tide. The correspondence of delivery time to the statistical time unit of effort being midnight to midnight depends on the synchronization of the two. An example, for clarification, would be the occurrence of high tide at 11:00 p.m. Only a certain proportion of those catches made on that day would be delivered before midnight and allocated to that day. Deliveries were assumed to be uniformly distributed over a 6-hour period, beginning 2 hours before high tide and lasting

Table 9. Variables defined for use in describing catchability as a function.

Variable	Variance explained due to:	Cause of such relationship
1. Effort in landings or boats	Association of catchability with effort	1. Competition or physical interference between units of gear. 2. Retention period greater than one day.
2. Day of the run	Association of catchability with time	1. Learning factor in fishermen. 2. Gradual change from "king" to "sockeye" gear.
	Association of catchability with abundance present	Catchability may vary with level of abundance as processor limitations and restrictions affect fishing. Abundance is assumed to vary with day of run.
	Association of catchability with sockeye salmon races late in season	Substantial catches persist after counting towers close, perhaps from later timed races bound for tributaries of Togiak and the main river below the tower.
3. Tide index	Different tidal patterns each day	With delivering of catch restricted to high tide, CPUE of days with differing amount of delivery time available are not comparable.
4. Landing per boat	Changes in the normal fishing pattern	1. On days of high abundance if landings per boat increase catchability will vary. 2. Influx later in season of small boats which consistently deliver each tide.

-Continued-

Table 9. Variables defined for use in describing catchability as a function (continued).

Variables	Variance explained due to:	Proposed relationship
Average daily sockeye salmon size as:	Selectivity of the gillnets	1. Gillnets select for an optimal size range which is superimposed on the distribution of fish sizes present. This interaction will vary as does the distribution here described by its mean.
5. Average weight from fish tickets		
6. Average length from A-W-L sampling		
7. Average weight from A-W-L sampling		

4 hours after. In this example, the majority of deliveries would be made from 9 p.m. to 3 a.m. Thus, with 50% of the delivery time available (9:00 p.m. - 12:00 a.m.), only 50% of that previous tide's catch could be delivered before midnight, resulting in a tide index of .50. Given that the previous delivery time about high tide was fully within the day, 1.0 is added. If the previous evening's high tide were at 10:00 p.m., the deliveries would be made from 8 p.m. to 2 a.m., and an index of .33 would be allocated to this day. The resulting tide index for the day would be 1.83. A full day's tidal cycle would receive an index of 2.0. This assumes the optimal fishing tide is low and beginning of the flood and optimal delivering tide becomes the high. If the time of each delivery were known for historical data, the unit of effort could be defined by delivery tide or per half day. This would negate the need for a tide index which attempts to compensate for the artificiality of a 1-day time period.

Landing per boat as a variable was postulated to be useful in describing the variance in catchability because of a less-than-ideal unit of effort. In theory, each standard unit of effort should take the same proportion of stock present. But, as happens in a skiff fishery, holding capacity is limited, and on days of high density, two deliveries per day may become necessary, one each tide. Thus, fishing time per delivery may vary with density and may be reflected by landing per boat. The variance in the CPUE relationship with daily abundance manifests itself in a varying catchability as the time unit of effort is fixed to be 1 day. Landing per boat could be an index of this and when greater than one, it indicates days in which there was a loss in available fishing time because of the time involved in a second delivery. There is also an influx later in the season of small boats (skiffs < 16 ft.) joining the fleet to fish the inner bay near the cannery (Figure 2) and consistently delivering every tide. Their presence and the resulting change in the fishing pattern could also be detected by an increase in landings per boat. Finally, the variable, landings per boat, could be viewed as an indicator of a type of saturation. Catch per unit effort will be associated with abundance, but at levels of high density, the catches could be somewhat lower than expected with a constant catchability because of the lost fishing time spent instead on an additional delivery per day. Landings per boat could be an indicator of this and might describe the variance in catchability attributable. Table 10 shows that the average landings per boat has varied little between years of interest or even between gear types where it was previously believed that set net fishermen delivered after each tide.

It has been documented by the test fisheries of Bristol Bay (Yuen 1980) and other sampling programs using gill nets (Regier and Robson 1966; Todd and Larkin 1971) that catchability varies with fish size. The nets have been shown to be size-selective and the relationship with the season's average-sized fish might vary yearly. In-season daily fish size can be obtained from different sources. Initially, the day's catch is reported by the processors in numbers and pounds, facilitating an average weight from commercial reports. In addition, ADF&G maintains an age, weight, and length (AWL) sampling program in Togiak from which the average weight or length can be obtained. Thus, three types of daily size indicators were evaluated, first the daily mean weight from commercial fish tickets, second the mean length from A-W-L samples, and lastly, the mean weight of A-W-L samples.

Table 10. Daily average number of landings per ADF&G license holder (L/B) fishing in Togiak Bay.

Date	Daily average number of landings per boat					
	All gear		Drift nets		Set nets	
	L/B	SD[1]	L/B	SD	L/B	SD
1976	1.16	0.02	1.14	0.02	1.23	0.06
1977	1.24	0.02	1.21	0.01	1.33	0.05
1978	1.19	0.01	1.18	0.01	1.25	0.05
1979	1.20	0.01	1.18	0.01	1.25	0.03
1980	1.18	0.01	1.14	0.02	1.29	0.03

[1] SD = standard deviation.

In summary, a number of variables were proposed to compensate for the crude unit of effort available in a commercial fishery. If the actual fishing time and tidal stage for each catch were known daily, landings per boat and the tide index would be unnecessary, as effort could be adjusted accordingly, leaving catchability constant. In essence, the unit of effort has been forced to be constant or unadjustable, resulting instead with adjustments in catchability for a useful relationship with which to estimate daily abundance and escapement.

Initially, a linear model was hypothesized for catchability which could be solved in obtaining least squares estimates of coefficients by regressing daily catchability (q_i) on the previously mentioned variables (X_{ij}):

$$q_i = B_0 + \sum_{j=1}^{5} B_j X_{ij} + e_i$$

There exist seven variables (X_j) where only one size indicator is entered at a time. The variables were plotted against catchability for an indication of the strength of any relationship. Only effort (Figures 9 and 10) appears to be associated with catchability to any great extent.

The correlation matrix resulting from a stepwise regression (Draper and Smith 1966) on catchability (Table 11) shows effort, landings per boat (L/B) and the tide index (T) to be the most highly correlated with catchability. Three regressions were conducted, each including one variable representing fish size. Effort is the next highly correlated and enters the regression equation first. Next, L/B and the tide index are confounded with effort which substantially decreased their effectiveness in describing additional variance of catchability given that effort had entered the equation. Thus, only the coefficients (B_j) of effort and day of the run differed significantly from zero (Table 12). This resulted in the explanation of 74% of the variation in catchability while effort explained a substantial 70%. Still, in this choice of model to estimate catchability there appeared a non-randomness to the runs of signs of the residuals (Draper and Smith 1966, 1980) and a different model was sought.

The slight association with time, though accounting for the explanation of only 4% of the variation, did suggest an alternative model. A matrix consisting of all the data was created with columns representing years, and rows representing day of the run. From this a natural breakdown by week of the run became apparent. This would accomplish much of what the previous significant time variable did as there is now a type of blocking on time. This allows for the separation out of the first week of the run where fishing is most apt to be of mixed gear types ("king" and "sockeye"). One can also isolate the second week in which during 1976 and 1978-80, processor limitations changed the fishing pattern. In 1976, catch limits were imposed and buying suspended during 5-10 July. In 1978, limits were placed on fishermen delivering to the primary land-based processors. Floaters did take up the excess, but it still decreased remaining fishing time by the amount necessary for an additional delivery and artificially increased the number of landings per day. Catchability is artificially lowered with limits and suspended buying and this data needs to be separated from that remaining. Processor limitations are less likely the third week but data should be separated from the fourth week. During the fourth week there is

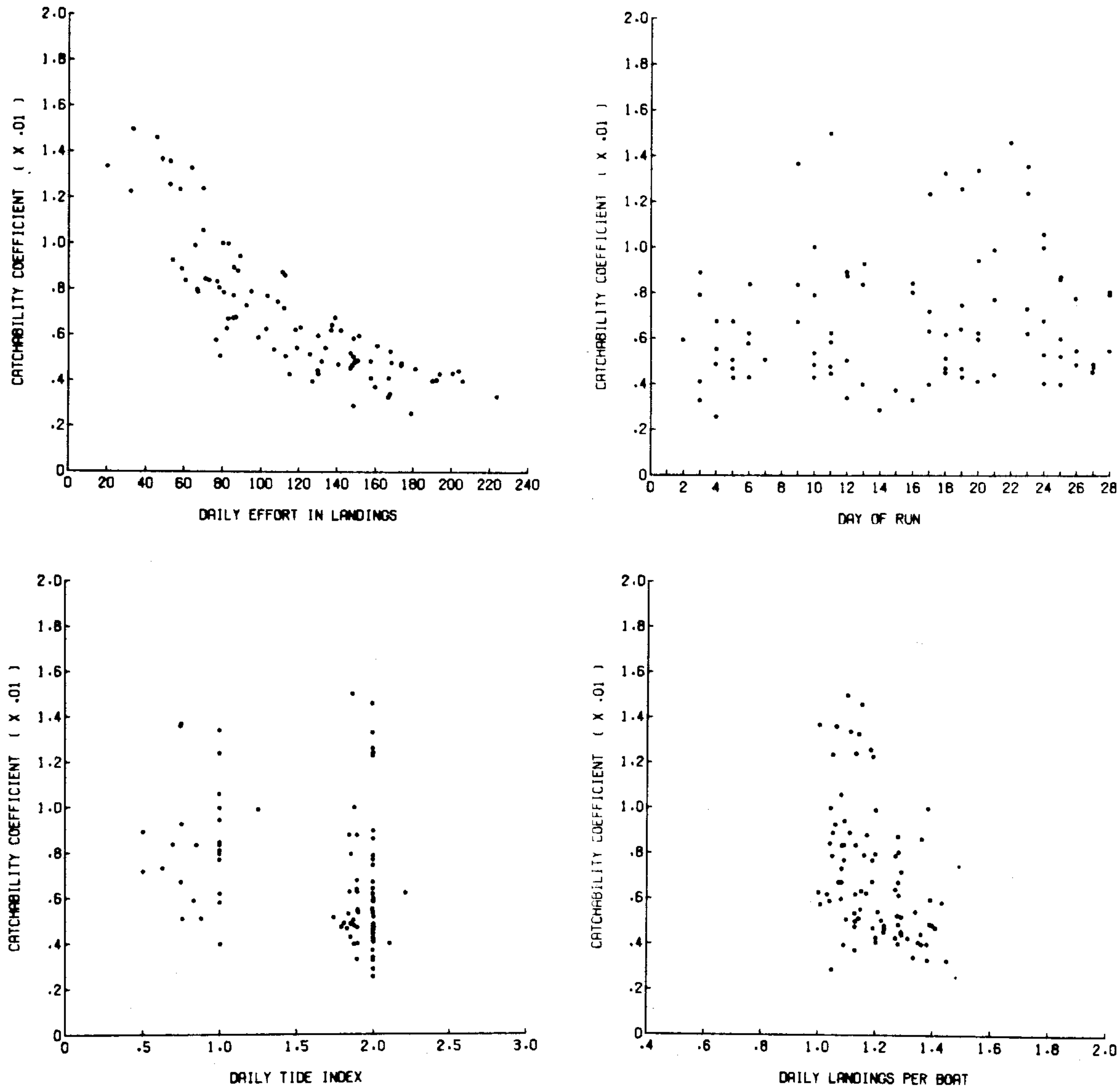


Figure 9. The catchability coefficients calculated from historical data of the Togiak Bay sockeye salmon fishery, 1976-1980, and their subsequent relationship to the following variables: Effort in landings, day of run, landings per boat, and tide index.

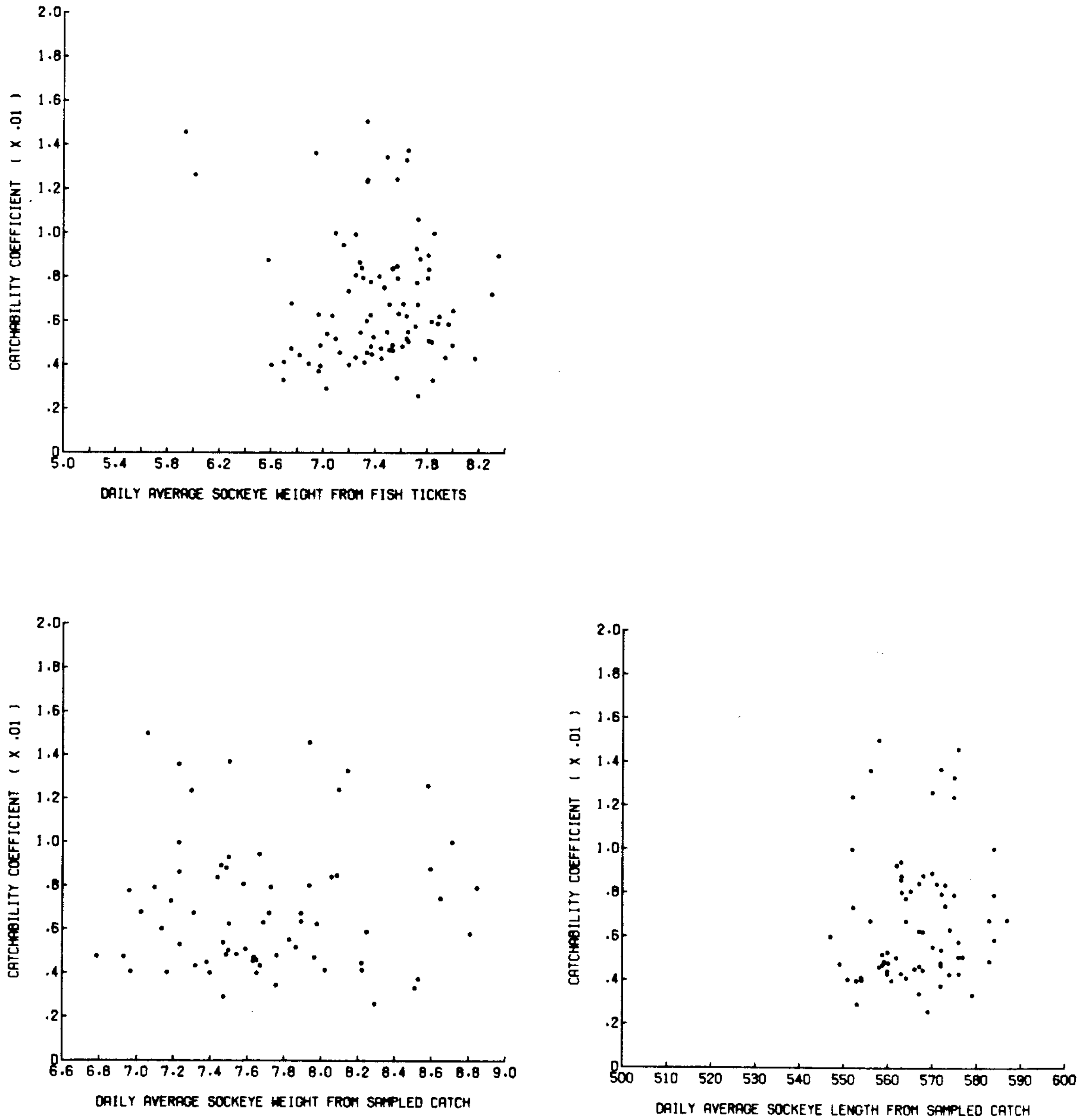


Figure 10. The catchability coefficients calculated from historical data of the Togiak Bay sockeye salmon fishery, 1976-1980, and their subsequent relationship to the three variables representing fish size: Average sockeye weight from fish tickets, average sockeye weight from AWL catch samples, and average sockeye length from AWL catch samples.

Table 11. Correlation coefficients (r) for three regressions of catchability (q), each with a different fish size variable. Differing size data sets for fish size variables are reflected in the differing r values of variables between regressions.

Effort (F)	-0.84				
Day of run (D)	0.18	0.03			
Tide index (T)	-0.34	0.53	0.14		
Landings per boat (L/B)	-0.43	0.58	0.22	0.46	
Daily mean sockeye salmon weight from fish tickets	-0.08	-0.12	-0.49	-0.25	-0.07
	Q	F	D	T	L/B

F	-0.81				
D	0.17	0.07			
T	-0.31	0.52	0.06		
LB	-0.41	0.56	0.21	0.42	
Daily mean sockeye salmon length from AWL sample	0.10	-0.25	-0.61	0.02	-0.07
	Q	F	D	T	LB

F	-0.84				
D	0.12	0.07			
T	-0.32	0.51	0.08		
LB	-0.40	0.57	0.30	0.41	
Daily mean sockeye salmon weight from AWL sample	0.02	-0.02	-0.33	0.08	0.04
	Q	F	D	T	LB

Table 12. Results of linear regression for catchability where effort in landings per day was used.

Regression with catchability for:		Variables available for entry into linear regression with catchability: Effort	Day of run	Tide index	Landings per boat	Mean daily weight[b]	AWL mean daily len.	AWL mean daily wt.
	Sign.[a]	S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.
Entire year	R^2	0.70	0.74					
	ΔR^2	0.70	0.04					
	Sign.	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
1st Week	R^2	0.67						
	ΔR^2	0.67						
	Sign.	S.	N.S.	N.S.	N.S.	S.	N.S.	N.S.
2nd Week	R^2	0.75				0.81		
	ΔR^2	0.75				0.06		
	Sign.	S.	N.S.	N.S.	N.S.	S.	N.S.	N.S.
3rd Week	R^2	0.79				0.83		
	ΔR^2	0.79				0.04		
	Sign.	S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.
4th Week	R^2	0.82	0.88					
	ΔR^2	0.82	0.06					

[a]Sign. = significant at the 95% level.
S. = significant at the 95% level.
N.S. = not significant.
R^2 = coefficient of determination.
ΔR^2 = change in R^2 due to addition of variable.

[b]From fish tickets.

often a transfer in of additional vessels as other Bristol Bay fisheries decline. These are primarily 32 ft (9.76 m) vessels and may differ in efficiency from the local skiff fishermen. Also, as mentioned earlier, there arises the likelihood of the presence of sockeye salmon bound for the lower tributaries and the main Togiak River channel which are not counted in-season by the towers. Their presence in the catch will artificially increase catchability.

In the linear regression of catchability by week (Table 12), effort again explained the most variation per week and was the only variable consistently significant. Day of the run was significant only for the fourth week explaining an additional 6% of the variation. When boats as a unit of effort was used, the tide index explained a significant amount of variation during the third and fourth week (Table 13). The mean daily weight from fish tickets was not consistently significant through the weeks, explaining about 5% in the third and fourth week. Use of the daily average length or weight of sockeye salmon from the A-W-L samples did not explain a significant amount of variation at any time.

The regression of catchability with effort alone was then conducted to examine the residuals for an evaluation of the adequacy of the model. A trend was apparent (Figure 11) as the residuals increased with increasing effort in excess of one hundred units and decreased over the range 0-100. A curve was then thought to better describe the relationship between effort and catchability. Intuitively, a curve is more appealing as one would expect a diminishing decrease in catchability with an increase in effort and not for catchability to be driven to zero as a linear expression suggests. Two models were postulated as having the necessary shape, a power curve $q_i = af_i^b$ and a negative exponential curve $q_i = ae^{bf_i}$ where $b < 0$ and a,b are regression coefficients (Tables 14, 15; Figures 12, 13, 14). The fit of the curves was substantially better than the linear model, especially in the behavior about the tails of the data. Plots of the residuals against all variables did not strongly indicate the addition of any other variable into the equation. Both a transformation of the data to a linear model and a nonlinear analysis were conducted of the curves to include all covariates. Variables were added in a multiplicative manner for a log transformation in the linear analysis as:

$$q_i = a\Pi_{j=1}^{5} X_{ij}^{b_j}$$

and:

$$q_i = a \ exp \ (\sum_{j=1}^{5} b_j X_{ij})$$

For the nonlinear analysis in addition to the above models, the variables were also added to the curves in a linear fashion:

$$q_i = a_1 f_i^{b_1} + \sum_{j=2}^{5} b_j X_{ij}$$

Table 13. Results of linear regression for catchability where effort in boats per day was used.

Regression with catchability for:		Variables available for entry into linear regression with catchability						
		Effort	Day of run	Tide index	Landings per boat	Mean daily weight[b]	AWL mean daily len.	AWL mean daily wt.
Entire year	Sign.[a]	S.	S.	S.	N.S.	N.S.	N.S.	N.S.
	R^2	0.68	0.74	0.76				
	ΔR^2	0.68	0.06	0.02				
1st Week	Sign.	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	R^2	0.48						
	ΔR^2	0.48						
2nd Week	Sign.	S.	N.S.	N.S.	N.S.	S.	N.S.	N.S.
	R^2	0.75				0.80		
	ΔR^2	0.75				0.05		
3rd Week	Sign.	S.	N.S.	S.	N.S.	N.S.	N.S.	N.S.
	R^2	0.80		0.85				
	ΔR^2	0.80		0.05				
4th Week	Sign.	S.	S.	S.	S.	N.S.	N.S.	N.S.
	R^2	0.79	0.87	0.94	0.92			
	ΔR^2	0.79	0.08	0.02	0.05			

[a]Sign. = significant at the 95% level.
S. = significant at the 95% level.
N.S. = not significant.
R^2 = coefficient of determination.
ΔR^2 = change in R^2 due to addition of variable.
[b]From fish tickets.

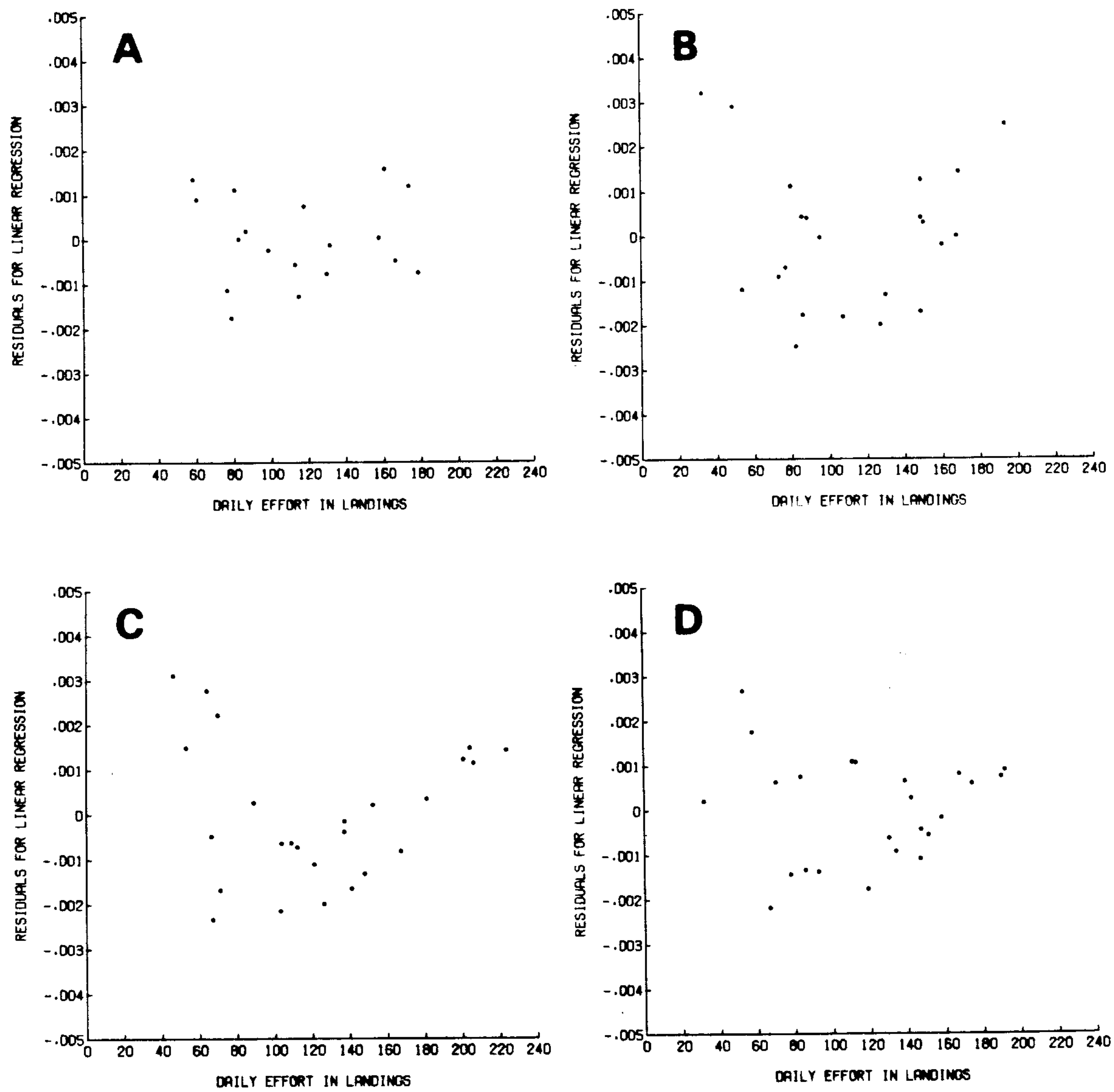


Figure 11. Residuals from the linear regression of catchability on effort by week for the Togiak Bay sockeye salmon fishery, 1976-1980. Week one (A), week two (B), week three (C), and week four (D).

Table 14. Statistics from the regression of catchability on daily landings as effort using three different models.

Week		Linear	Curves[a] Power	Exponential
1	R^2	0.67	0.73	0.70
	SD	1.0×10^{-3}	9.1×10^{-4}	9.6×10^{-4}
2	R^2	0.75	0.86	0.85
	SD	1.7×10^{-3}	1.2×10^{-3}	1.3×10^{-3}
3	R^2	0.79	0.90	0.88
	SD	1.5×10^{-3}	1.1×10^{-3}	1.2×10^{-3}
4	R^2	0.82	0.78	0.84
	SD	1.2×10^{-3}	1.4×10^{-3}	1.1×10^{-3}
Entire year	R^2	0.70	0.78	0.78
	SD	1.6×10^{-3}	1.4×10^{-3}	1.4×10^{-3}

where: R^2 = coefficient of determination.
SD = standard deviation.

[a]Results from nonlinear regression presented.

Table 15. Statistics from the regression of catchability on daily boats as effort using three different models.

Week		Linear	Curves[a] Power	Exponential
1	R^2	0.48	0.62	0.53
	SD	1.2×10^{-3}	1.0×10^{-3}	1.1×10^{-3}
2	R^2	0.75	0.84	0.84
	SD	1.7×10^{-3}	1.4×10^{-3}	1.4×10^{-3}
3	R^2	0.80	0.87	0.85
	SD	1.6×10^{-3}	1.3×10^{-3}	1.4×10^{-3}
4	R^2	0.79	0.72	0.80
	SD	1.4×10^{-3}	1.6×10^{-3}	1.4×10^{-3}
Entire year	R^2	0.68	0.74	0.74
	SD	1.8×10^{-3}	1.6×10^{-3}	1.6×10^{-3}

where: R^2 = coefficient of determination.
SD = standard deviation.

[a]Results from nonlinear regression presented.

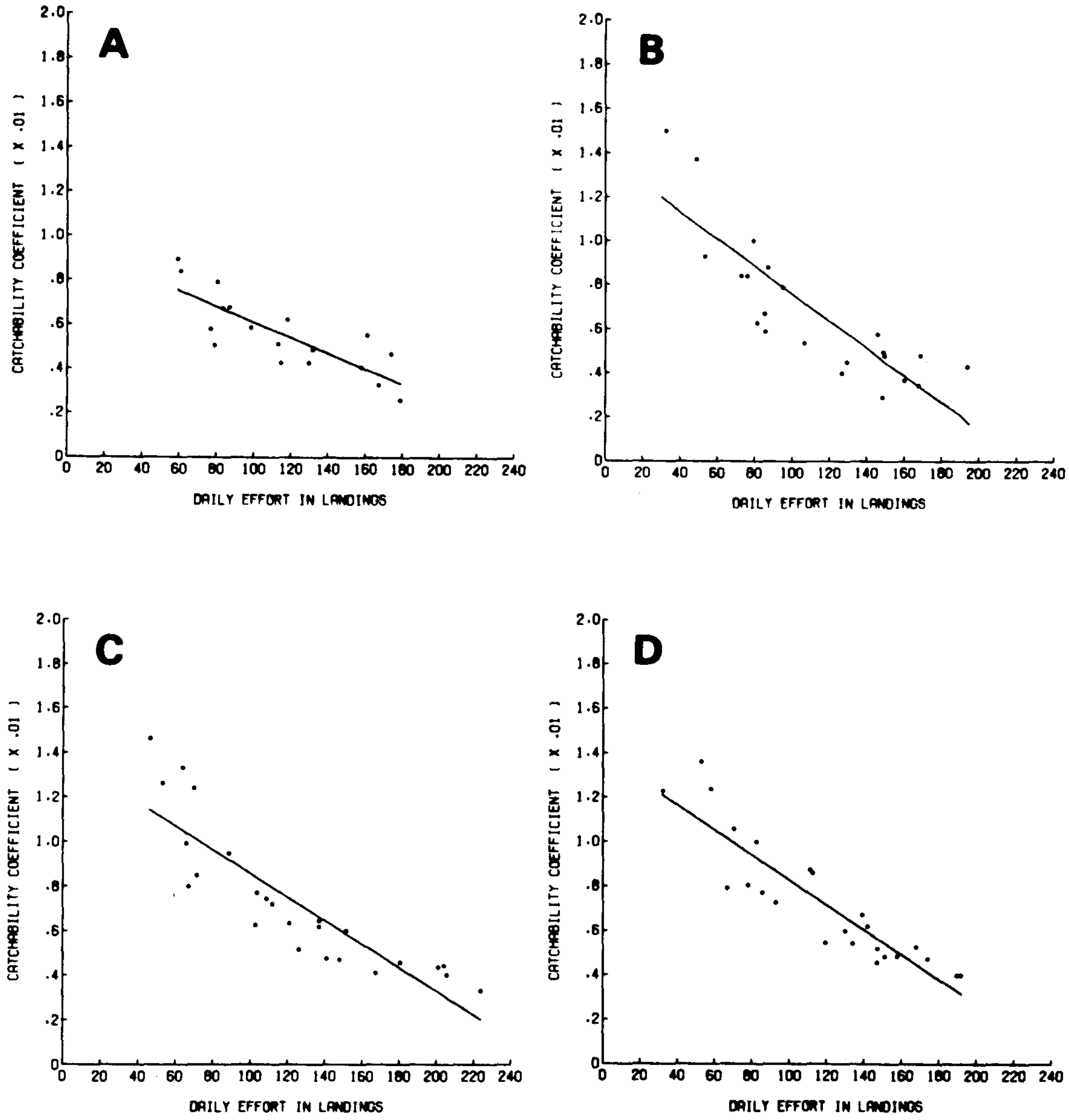


Figure 12. The linear regression of catchability on effort by week for the Togiak Bay sockeye salmon fishery, 1976-1980. Week one (A), week two (B), week three (C), and week four (D).

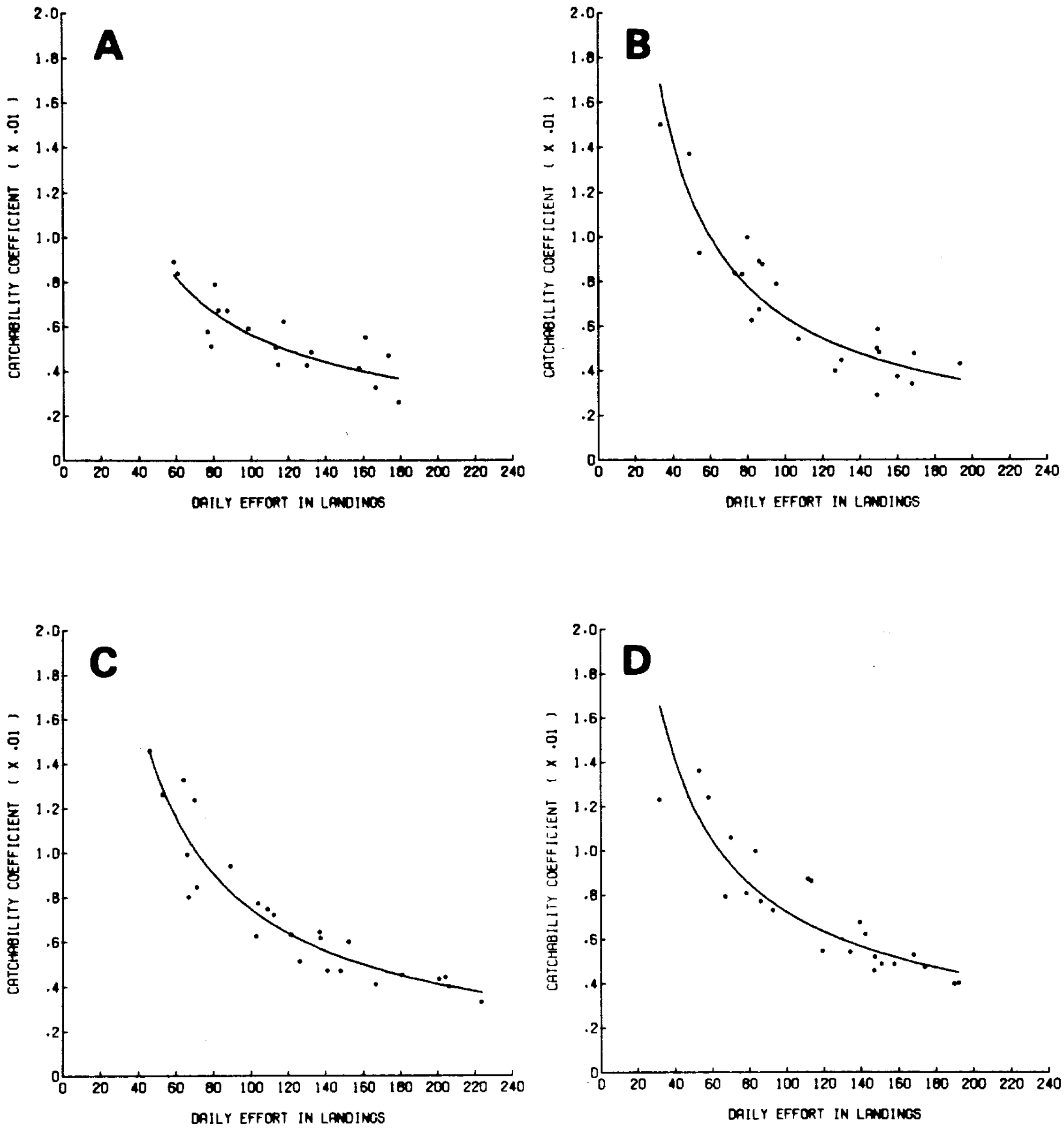


Figure 13. The regression of catchability on effort by week using the power curve model for the Togiak Bay sockeye salmon fishery, 1976-1980. Week one (A), week two (B), week three (C), and week four (D).

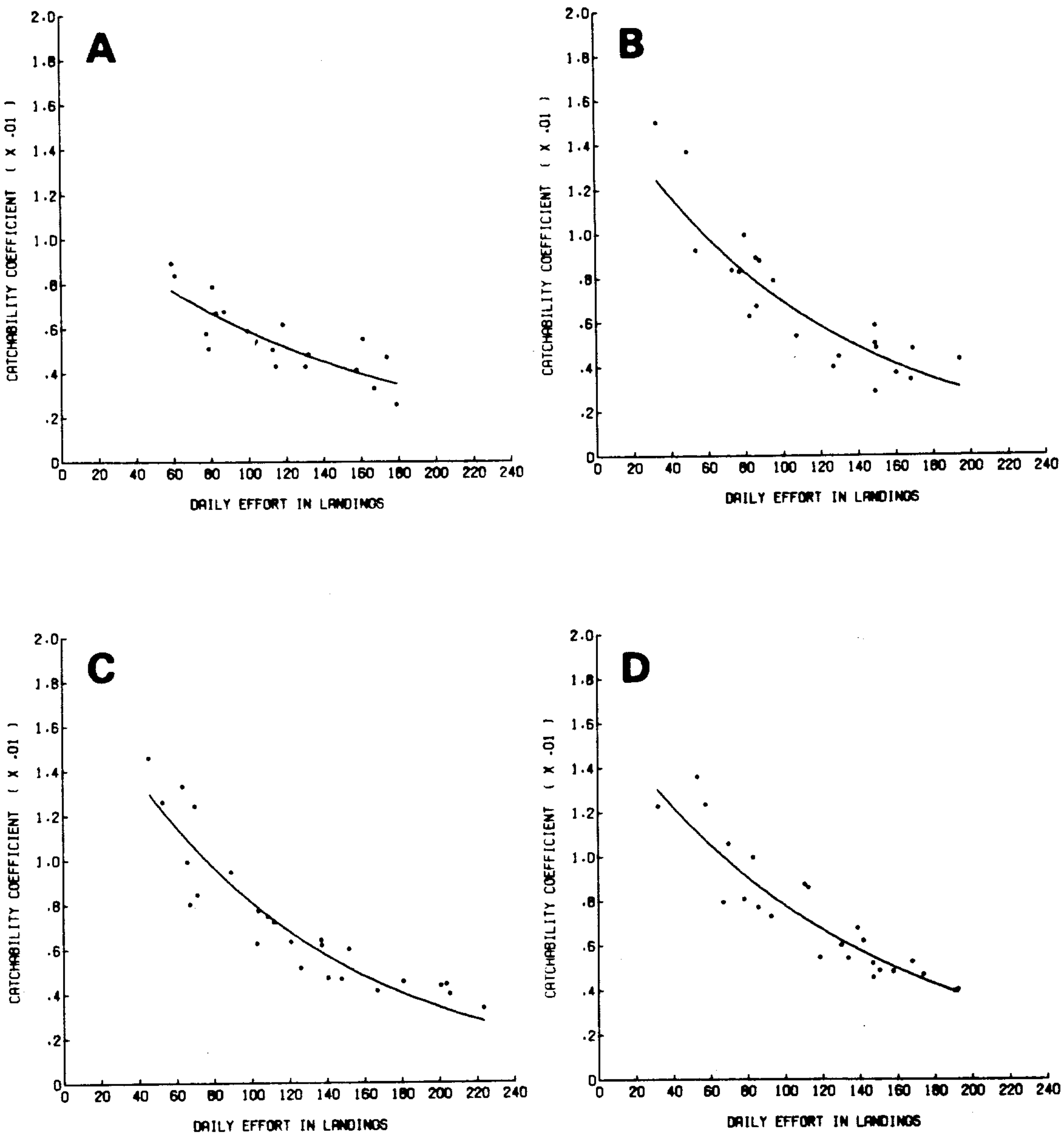


Figure 14. Regression of catchability on effort by week using a negative exponential model for the Togiak Bay sockeye salmon fishery, 1976-1980. Week one (A), week two (B), week three (C), and week four (D).

and:

$$q_i = a_i exp(b_1 f_1) + \sum_{j=2}^{5} b_j X_{ij}$$

Only the variables which explained more than 5% of the variation of catchability were analyzed by nonlinear regression after the linear transformation and again no variable other than effort was significant over all the weeks. In summary, only effort explained more than 5% of the variation in catchability for all weeks. The power curve was judged the best fit to the data in that it had the consistently largest coefficient of determination (R^2) with landings as effort, it also better described catchability for large values of effort.

As no variable representing fish size was consistently significant for data from the Togiak sockeye salmon fishery, an explanation was sought in the behavior of its selectivity curves. Although the "sockeye gear" commonly used in Bristol Bay is 5-3/8 in (13.6 cm) mesh, Togiak sockeye salmon are consistently the largest in Bristol Bay (ADF&G Annual Management Report, Bristol Bay area 1976). To visualize the sensitivity of catchability to changes in average fish size, length selectivity curves based on ADF&G A-W-L data were calculated for a given year. Escapement samples were used to apportion total escapement into length categories (i) as was total catch apportioned by its sample. These were then added together to create a total run in each length category (N_i) from which a selectivity coefficient (S_i) was calculated (Figure 15). Here the selectivity coefficient represents the fraction of the total run in a given length category caught by one average unit of gear. One would expect it to be constant across all length categories if the gear were not selective. One can see for the years 1976 to 1980 (Figure 15) that although the curves differ in height, their shape is essentially the same and average length differed little between years (Table 16). It appears that little selection by size occurs over the range 440-600 mm as demonstrated by the flatness of the curves in this region. If the mean size of sockeye salmon remains in the historically observed range, size may not affect catchability.

Curves of exploitation by length category (E_i) were also derived as a relative means of viewing selectivity curves (Figure 16). Here percent exploitation represents the fraction of total run in each length category which is caught. The curves differ in height because of different total exploitation between years and again differ very little in shape. There appears to be no displacement of the average sized fish in the catch from that of the total run (Table 16). Thus, as long as average fish size stays within the range observed here, catchability may not vary with fish size. Data should be tested in subsequent years to see if fish size describes variance in catchability as the distribution of size in the sockeye salmon population may change through time. Selectivity and length curves for the years 1972-1974, and not discussed in the text, can be found in Appendix B.

Interpolation Function for Estimating Escapement During Closed Periods

Due to the structure of the normal fishing period (9 a.m., Monday through 9 a.m., Friday), there exists a closure to fishing on Saturday and Sunday for which no estimate of escapement from CPUE can be made. For the escapement estimation process to be complete, some means of interpolating escapement of Saturday and Sunday from data of Friday and Monday were deemed necessary.

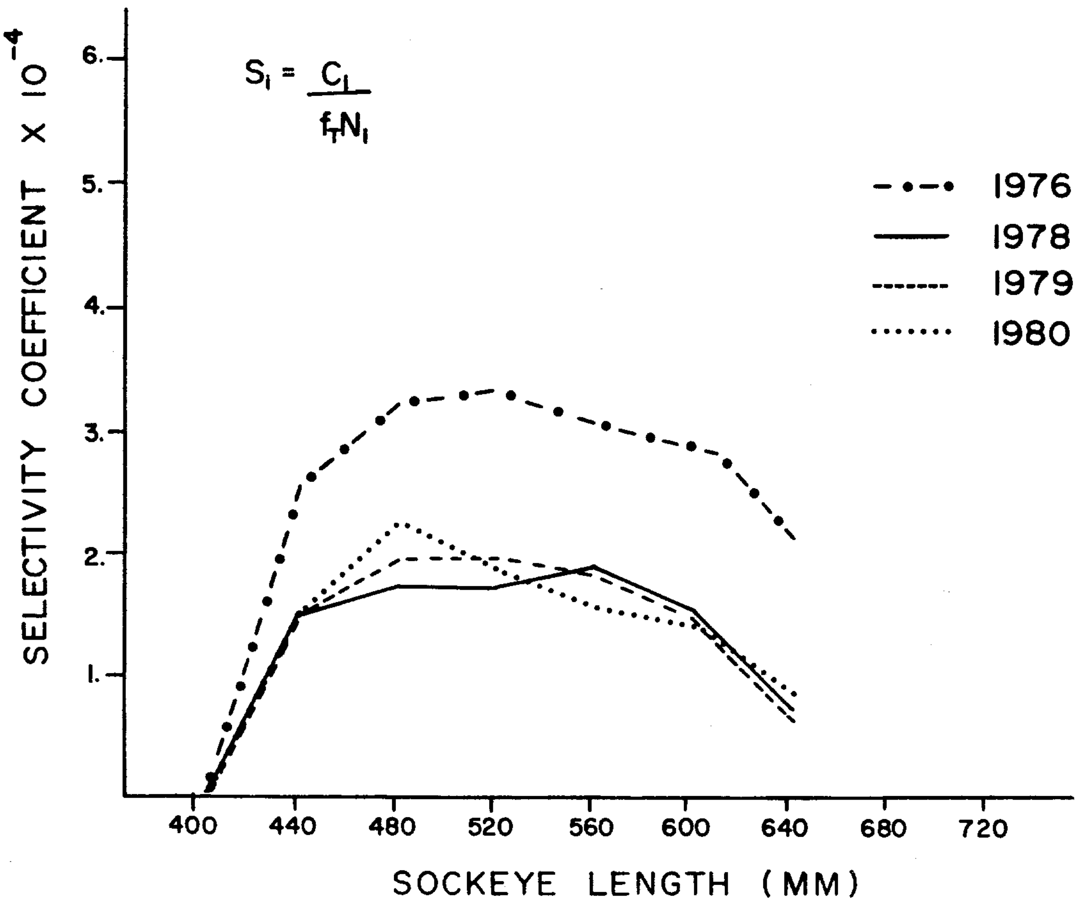


Figure 15. Selectivity curves for Togiak Bay sockeye salmon, 1976-1980. Fish length is measured from mid-eye to fork of tail. Sufficient data were not available for 1977.

Table 16. Length statistics from the Togiak River sockeye salmon run. Fish have been measured from mid-eye to fork of tail.

Year	Mean length (mm) based on AWL samples		
	Catch	Escapement	Total run
1976	552	558	554
1978	546	550	547
1979	539	554	543
1980	541	550	545

Sufficient data not available for 1977.

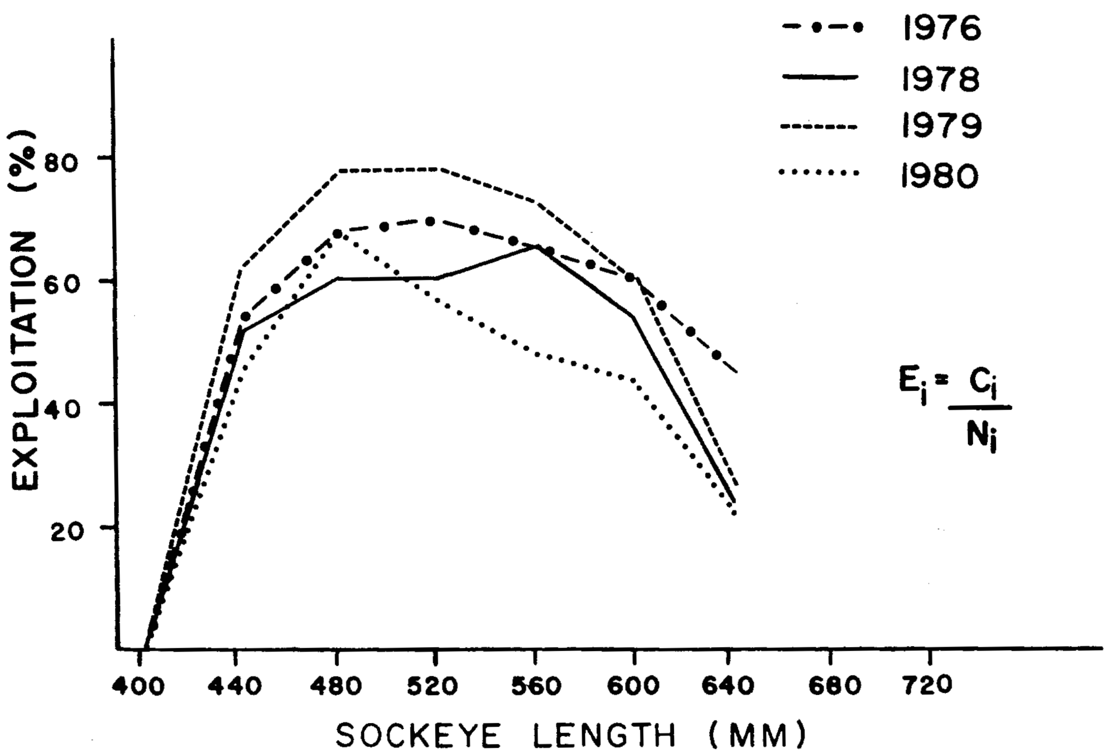


Figure 16. Exploitation by length curves for Togiak Bay sockeye salmon, 1976-1980. Fish length is measured from mid-eye to fork of tail. Sufficient data were not available for 1977.

A relationship for escapement during closed periods was sought from historical data. A multiple regression was conducted where the daily escapement during the closed period was the response variable and the independent variables were daily abundance, catch, and escapement of the closest day open to fishing. It was found that daily escapement of the closest day open to fishing was the only significant variable. Thus, for a weekend (2-day closure) or 3-day closure) a linear relationship incorporating escapement of the closest fishing day would estimate the escapement of closed periods (Table 17). If a 4-day closure occurs, a linear interpolation is suggested as a significant regression could not be developed from historical data. In calculating the regression equation historical data were used such that the independent variables were assumed to be measured without error and the assumption of linear regression upheld. An additional assumption is embedded in this regression in that a constant lag time was used to determine which day's escapement, as represented by tower counts, occurred on days closed to fishing. In contrast for its use, in-season escapement during the closest fishing day is itself an estimate with variance. Though it is still appropriate to use the relationship, any confidence interval will have a downwards bias if based only on the regression when viewing escapement as being measured without error.

The large R^2 values and the appropriateness of the model becomes apparent in viewing Saturday's escapement versus Friday's (Figure 17) and Sunday's escapement versus Monday's (Figure 18) with the resulting regression line. For a 3-day closure, the escapement of the third day was found to best estimate the unknown escapement of the second day (Figure 19). Here, the first and third days' escapement would be treated as a Saturday or Sunday in their respective equations. In summary, the relationships developed here (Table 17) would be used to estimate escapement during closed period of the Togiak Bay sockeye salmon season in accordance with the estimation from CPUE.

<u>Variance and 95 Percent Confidence Limits for Daily Abundance and Escapement Estimates</u>

Given that daily abundance is defined as in the model derivation and that catchability is a function of effort, a variance and 95% confidence limits can be calculated for the escapement estimates. Initially, daily abundance (N_t) was estimated as:

$$\hat{N}_t = \frac{C_t}{\hat{q}_t f_t}$$

where C_t = catch of day t

f_t = effort of day t

$\hat{q}_t$ = catchability estimated for day t

Thus, daily abundance is a function of the variable, catchability, which was estimated from a regression equation with effort as the independent variable. The appropriate variance for a predicted value of catchability $(\hat{q}_t)$ made on the basis of a regression equation is:

Table 17. Relationships developed to estimate escapement during closed periods.

	Equation	n	SD	R^2	Usage for escapements of
1	$y = 0.8016\,x + 689.4$	23	1,597	0.84	y = Saturday x = Friday
2	$y = 1.18\,x - 337$	29	2,559	0.72	y = Sunday or 1 day closure x = Monday or first day of following fishing period
3	$y = 1.02\,x + 48.36$	6	1,025	0.92	y = middle day of 3-day closure x = following day
4	$y_i = \dfrac{y_{i+1} + y_{i-1}}{2}$	Not a least squares estimate			y_i = 2nd or 3rd day of a 4-day closure

where: n = sample size.
SD = standard deviation.
R^2 = coefficient of determination.

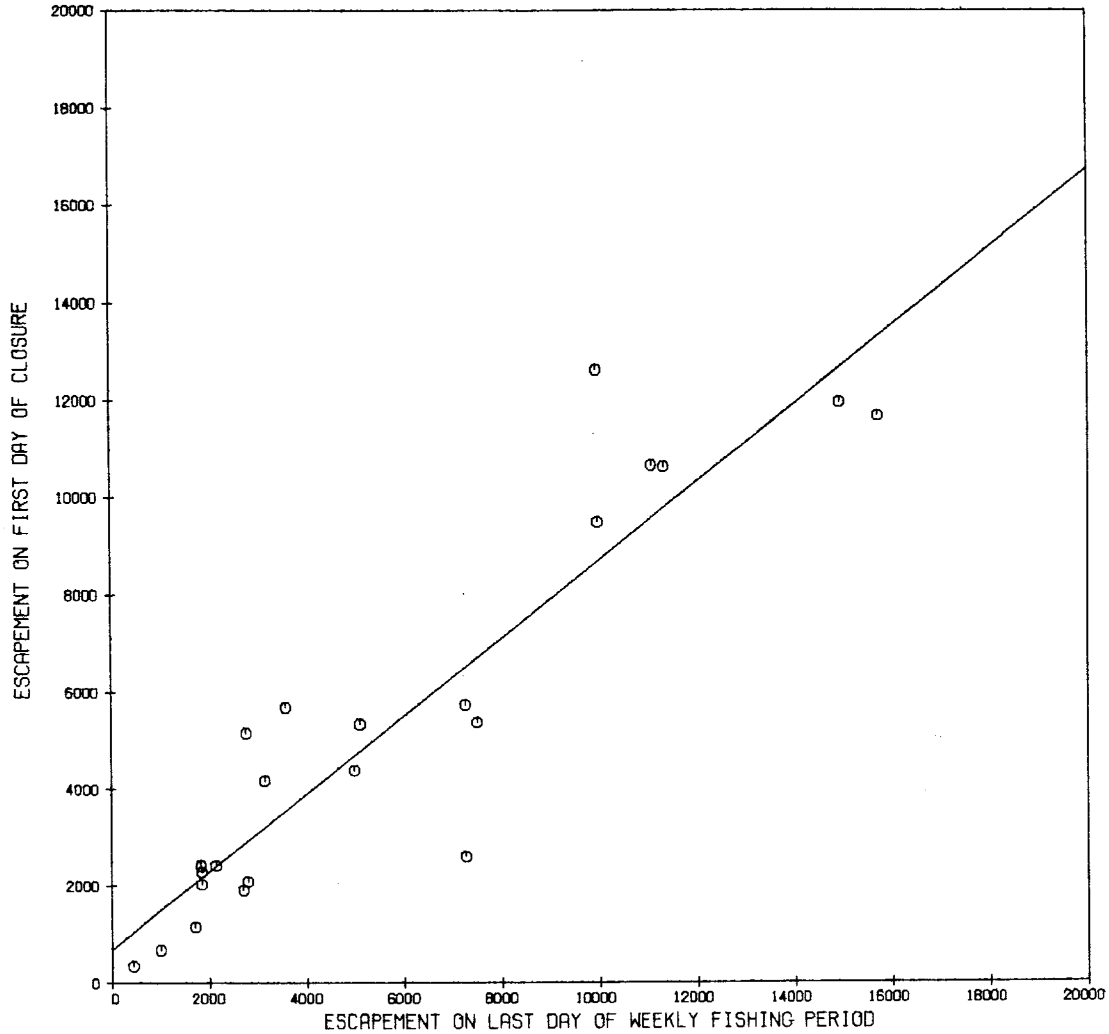


Figure 17. Relationship between Togiak River sockeye salmon escapement on the last day of the weekly fishing period, normally a Friday, and that of the first day of a closure, normally a Saturday.

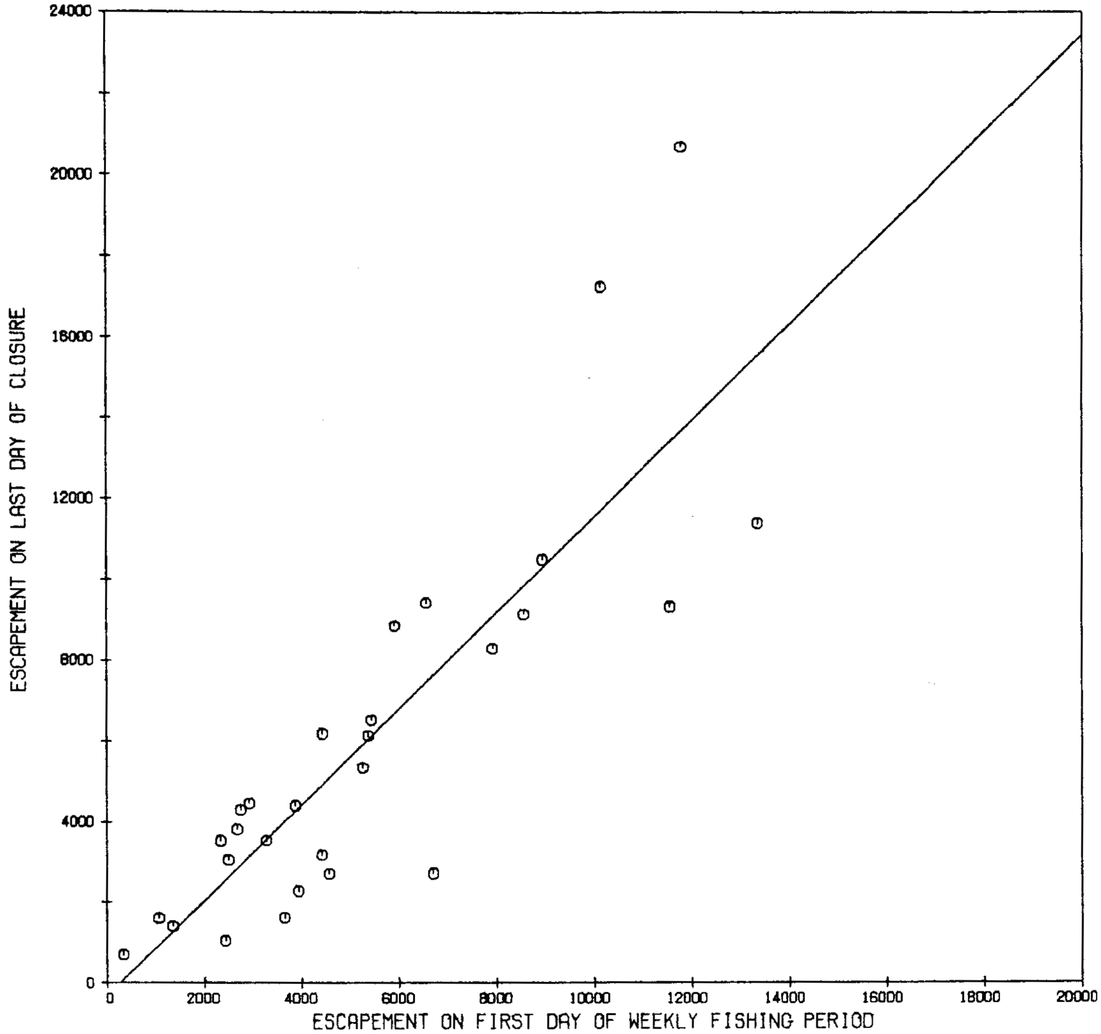


Figure 18. Relationship between Togiak River sockeye salmon escapement on the first day of the weekly fishing period, normally a Monday, and that of the last day of a closure, normally a Sunday.

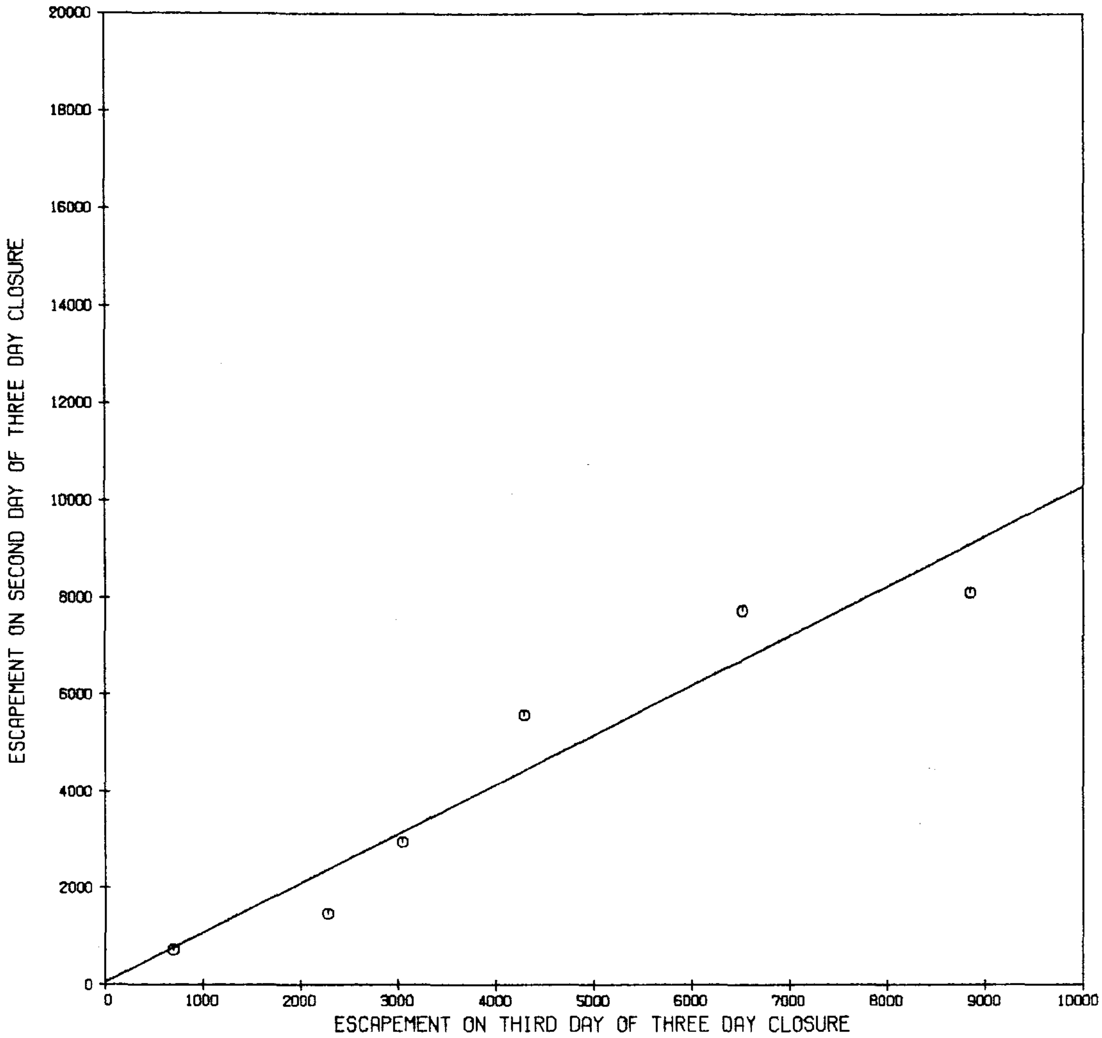


Figure 19. Relationship between Togiak River sockeye salmon escapement on the third day of a three-day closure and that of the second day of the same closure.

$$V(\hat{q}_t) = s^2_{q.f}\ [1 + \frac{1}{n} + \frac{(f_t - \bar{f})^2}{\sum_{j=1}^{n} (f_j - \bar{f})^2}\ ]$$

where:

$s^2_{q.f}$ = the unexplained mean square of residual variation of regression

n = sample size of regression

f_t = effort level of day t for $\hat{q}_t$

$\bar{f}$ = average level of effort for regression data $(f_j\text{'s})$

(Sokol and Rohlf 1969, p. 425).

The variance of the daily abundance estimate [$Var(N_t)$] can be estimated using the delta method (as discussed in Seber 1973, p. 7) as:

$$EV(\hat{N}_t) \approx V(\hat{q}_t) \left(\frac{d\ N_t}{d\ q_t}\right)^2 = \frac{N^4{}_t\ f_t^2\ V(\hat{q}_t)}{C_t^2}$$

For 95% confidence limits to be placed about the daily abundance estimate, it must be noted that the estimate is a function of the reciprocal normally distributed variable of the regression for catchability. Thus, estimates of daily abundance are themselves not normally distributed (DeLury 1951; Robson and Regier 1964) and confidence limits are best derived from the 95% confidence interval for catchability (q). Assuming it is asymptotically normal, the following probability (Pr) statement is true for a 95% confidence interval.

$$1.96 = \frac{Pr\ (|\hat{q}_t - E(q_t)|)}{\sqrt{V(\hat{q}_t)}}$$

Where $E(\hat{q}_t) = \dfrac{(\ C_t\ )}{f_t\ N_t}$, the bounds for the daily abundance

estimate become:

$$N_t(U,L) = \frac{C_t}{f_t \left[\hat{q}_t \pm (1.96\sqrt{V\ (\hat{q}_t)})\right]}$$

here the lower bound of daily abundance $[N_t(L)]$ is derived from the upper bound of daily abundance and vice versa.

The escapement estimates (E_t) then become:

$$E_t = N_t - C_t$$

thus: $V(N_t) = V(E_t)$ and the confidence interval becomes:

$$(E_{upper})_t = (N_{upper})_t - C_t$$

$$(E_{lower})_t = (N_{lower})_t - C_t$$

TOTAL RUN ESTIMATION

Background

Fisheries biologists and others of the fishing industry have long noted the consistency through generations of the arrival by time in given runs of sockeye salmon (Thompson 1951; Royal 1953; Vaughan 1954; Killick 1955; Gilhousen 1960; Smith 1964; Narver 1966; Bevan and Lechner 1970). Initially there evolved the concept of races, each with specific timing often not overlapping as between early and late runs to a given river. Then the goal to allow escapement from all races or segments of the run as composed as distinguishable or indistinguishable races (Thompson 1951; Smith 1964) was proposed. In systems of multiple races, the entry pattern as defined by the timing and percentage arrival by date was used to distinguish between them as necessary for fulfillment of differential harvest or escapement goals.

The timing of the arrival of a race of salmon has been described as the "entry pattern" (Dahlberg 1968), "curves of availability" (Royal 1953), "pattern of departure" (Bevan 1962) or "time abundance curves" (Gilhousen 1960). All have emphasized the correlation between date and the return of a certain proportion of total abundance of the year's run. Some have described this relationship of abundance versus time as being bell-shaped although possibly varying significantly from a normal curve (Royal 1953; Gilhousen 1960). It was seen that certain attributes of the time-abundance curves could vary yearly; such as date of peak abundance; shape as described by spread or dispersion; degree of symmetry or skew present; and presence or absence of bimodality. From the idea of the entry pattern being an identifiable attribute of a race of sockeye salmon came the proposition that it be used to estimate total run size in-season.

A relative measure was developed for the entry pattern as a historical average curve of cumulative proportions of catch or total run to date. Total run was then estimated to be the ratio of catch plus escapement to date over the cumulative proportion expected to date. Mundy (1979) took this approach a step further in modeling the migratory timing of sockeye salmon as a random variable. Relative abundance was calculated as the daily proportion of the total run observed by date. The random variable (T) was then associated with day of the run in that it mapped a particular calendar date to a day of the run where its probability of occurrence was the proportion of abundance expected during that interval $[f_T\ (t)]$. This function was found to conform to the criteria in one case of a discrete density function in that the function was non-negative for all time intervals (t), greater than zero for a finite number of intervals, and when summed across that time period, equaled one. It was termed a "migratory time-density function" in that the random variable maps time to day of migration with the probability measure being the expected proportion of total abundance. The distribution function of the random variable (T) then involves the cumulative proportion of total run expected to date $[F\ (t)]$. A migratory time density may be described in terms of a distance or continuous density function. Again, total run is estimated on a given day of the run (t) as:

$$Total\ Run = \frac{Catch + Escapement\ to\ Date}{F_T(t)}$$

where:

$F_T(t)$ = the probability of occurrence of $T \leq t$; as the expected cumulative proportion of the run to date.

In practice, the usefulness of the approach in-season will depend on the consistency of the entry pattern such that the mean curve or developed distribution will adequately describe a particular year.

Application of Migratory Time-Density Functions in Salmon Management

The sockeye salmon of the Skeena River, British Columbia, Canada, afforded Walters and Buckingham (1975) an entry pattern with which to test this idea. A discrete function approach was taken in that a historical average for years 1955-1973 was calculated from cumulative proportion returned to date. Data were averaged across calendar dates and no adjustment was made for early or late runs. Total run was estimated in-season as described previously.

In contrast, Mundy (1979) developed the concept of a "migratory time-density function", using data from Alaska's Bristol Bay sockeye salmon with in-season data collection by the Port Moller test fishery. The distribution function was described by the inverted exponential model:

$$F_t(t) = 1\ /\ [1 + exp\ (-\ [a + bt])]$$

with proper bounds. Yet Mundy did not rigidly set his function to serial date. He allowed run initiation to vary yearly so as to best match the shape of yearly entry curves where day one was not fixed to a calendar date. Estimates of the coefficients $(a,\ b)$ were then calculated using nonlinear regression with real data. Again, total abundance is estimated as the ratio of catch and escapement observed to date (t), over $F_T(t)$, the cumulative proportion expected to date. In Cook Inlet, Alaska, CPUE from a test fishery (Waltemyer et al. in press) is again used to obtain information on run timing. Estimates of incoming run size are estimated in conjunction with its migratory time-density function using the same model as in Bristol Bay.

In contrast in Nushagak Bay of Bristol Bay, Alaska, information on run timing and strength comes from the commercial fishery (Hornberger and Mathisen 1980). Here a normal curve was fit to the proportion of catch plus escapement from historical data for use as its migratory time-density function. In addition, a discrete view was taken in calculating a migratory time-density function as a historical average by day of run. As a result, the historical average was the preferred density used in-season. Again, date was coded and the first day of the run was allowed to vary in order to best match curves from years of differing run initiation. The concept of varying day one led to its definition here based on the attributes of the normal curve, in conjunction with in-season detection. It was defined as the maximum of the second derivative of the normal distribution which occurs when 4.18% of the run is accounted for. This is a point of maximum increase over this portion of the curve and would thus be helpful for in-season detection of the defined run initiation. There arises a difficulty in the in-season detection of day one where run initiation has been allowed to vary independently of calendar date, instead of being dependent upon expected cumulative proportion. However, the daily rate of change in catch plus escapement can be observed during the season and a maximum early in the season viewed as a rapid increase in catch and escapement is theorized to be day one of the migration. Total run size is estimated during the season similar to Mundy (1979).

Lastly, in Prince William Sound, Alaska (Roberson et al. 1978), daily escapement information was not available for all sockeye salmon systems such that a relationship was developed using catch data only. Cumulative catch by week is computed and total catch is then estimated as the ratio of observed catch to date over the expected proportion of total catch.

In summary, two approaches have been taken in developing a migratory time-density function. First, a continuous function (logistic or normal) was fit to historical data and used to calculated expected proportions by date (Mundy 1979; Waltemyer et al. in press; Hornberger and Mathisen 1980). Second, a discrete function approach has been taken in which historical data is averaged across calendar date (Walters and Buckingham 1975), week (Roberson et al. 1978), or day of the run (Hornberger and Mathisen 1980), for use as the migratory time-density function in total run estimation. Those in Bristol Bay have been successful in that the approaches are currently used during in-season management.

Development of a Migratory Time-Density Function for Togiak Bay Sockeye Salmon

The Togiak Bay sockeye salmon fishery has several elements in common with some of the areas of previous migratory time-density application. It is a terminal area fishery where sampling is done by the fishing fleet as in Nushagak Bay. It also occurs in an estuarine environment where there may be delay before upstream migration, as observed in the Skeena River (Walters and Buckingham 1975). In both applications it was found that a historic average performed better than a particular function fit to the data.

In the development and use of a migratory time-density function in total run estimation, two assumptions have been stressed. Most important is the assumption that migratory behavior as the pattern of arrival and departure of the salmonid species of interest is conserved across generations. Secondly, it is assumed that we are dealing with a single life history stage during which the fish are observed to migrate in the same direction past a given reference point. In application for the Togiak River, the adult salmon are assumed to be returning to their place of birth. They are merely migrating through the fishing grounds where they are being sampled by the fishery from which an estimate of daily abundance is made (see above section on Proposed Model to Estimate Daily Abundance). Any milling or delay of the fish in the district defined as a retention period greater than 1 day would not fulfill the second assumption. The sockeye salmon then being sampled would not all be actively migrating in the same direction. In theory, this could be observed as the occurrence of a daily abundance on days with no fishing consistently less than on days with fishing. Here, daily abundance is observed as catch plus escapement. If no milling occurred, escapement during closed periods would be expected to increase over days with fishing by an amount similar to that being caught.

To illustrate the influence of a weekly fishing pattern and a retention period greater than 1 day, assume the sockeye salmon enter the Togiak District following a normal distribution with a mean of 13.5 and a variance of 32.82. A distribution fit by Hornberger et al. (1979) to the 1979 sockeye salmon run into Nushagak Bay will be used for a run of 100,000 sockeye salmon. Four arbitrary milling schemes were then assumed for sockeye salmon before entering the Togiak River. The first involved a distribution of upriver departures where all were available the first day, after which 20% escaped upriver; 60% at the end of the second day, and the remaining the end of the third. The second one involved a longer retention period where 10% departed the end of the first day, 20% the second, and the remaining the end of the third. The last two involve an exponential departure rate $exp(-dt)$ where all have escaped at the end of a 2- or 4-day period, accepting a 5% error bound. The literature seems to support a negative exponential departure (Mathisen 1969). Superimposed on this estuary system is a 50% daily exploitation rate by a fishery operating 5 days per week (Monday through Friday). Arrivals are assumed instantaneous (Ricker 1975), occurring at the beginning of each day. As can be seen in Figure 20, there is a substantial difference between the normal pattern of arrival and that created by adding catch plus escapement when the retention period is greater than 1 day. There exists a "building up" of fish through the weekend closure resulting in large catches and thus a large daily abundance being assigned to Monday. The resulting entry pattern from catch plus escapement is sine-soidal with troughs created during closed periods.

Interestingly, the entry pattern created by catch plus escapement for Togiak Bay sockeye salmon is just such a sinuate curve where troughs occur during closed periods (Figures 21 to 24). These curves not presented in the text can be found in Appendix C. The entry patterns were reconstructed as the daily abundances (see above section on Proposed Model to Estimate Daily Abundance) calculated in the lag time analysis and converted to daily proportions of total for a relative measure. This sinuate pattern most likely indicates a retention period greater than 1 day. Yet one cannot infer from the illustration the actual pattern of arrival to be normal or the particular mechanics of the milling behavior. Just as a change in the average stay of sockeye salmon changed the entry pattern calculated from catch plus escapement so would a change in either the pattern of fishing periods or the arrival distribution. The entry patterns can be grouped by the fishing patterns that influenced them. Most common is the pattern of 4 week-long fishing periods with weekend closures (Figures 21 and 22). This presents the sinuate entry pattern as previously discussed. A second but less common occurrence is that of continuous fishing (1980 in Figure 23) or of a prolonged closure (1972 in Figure 24). Here one

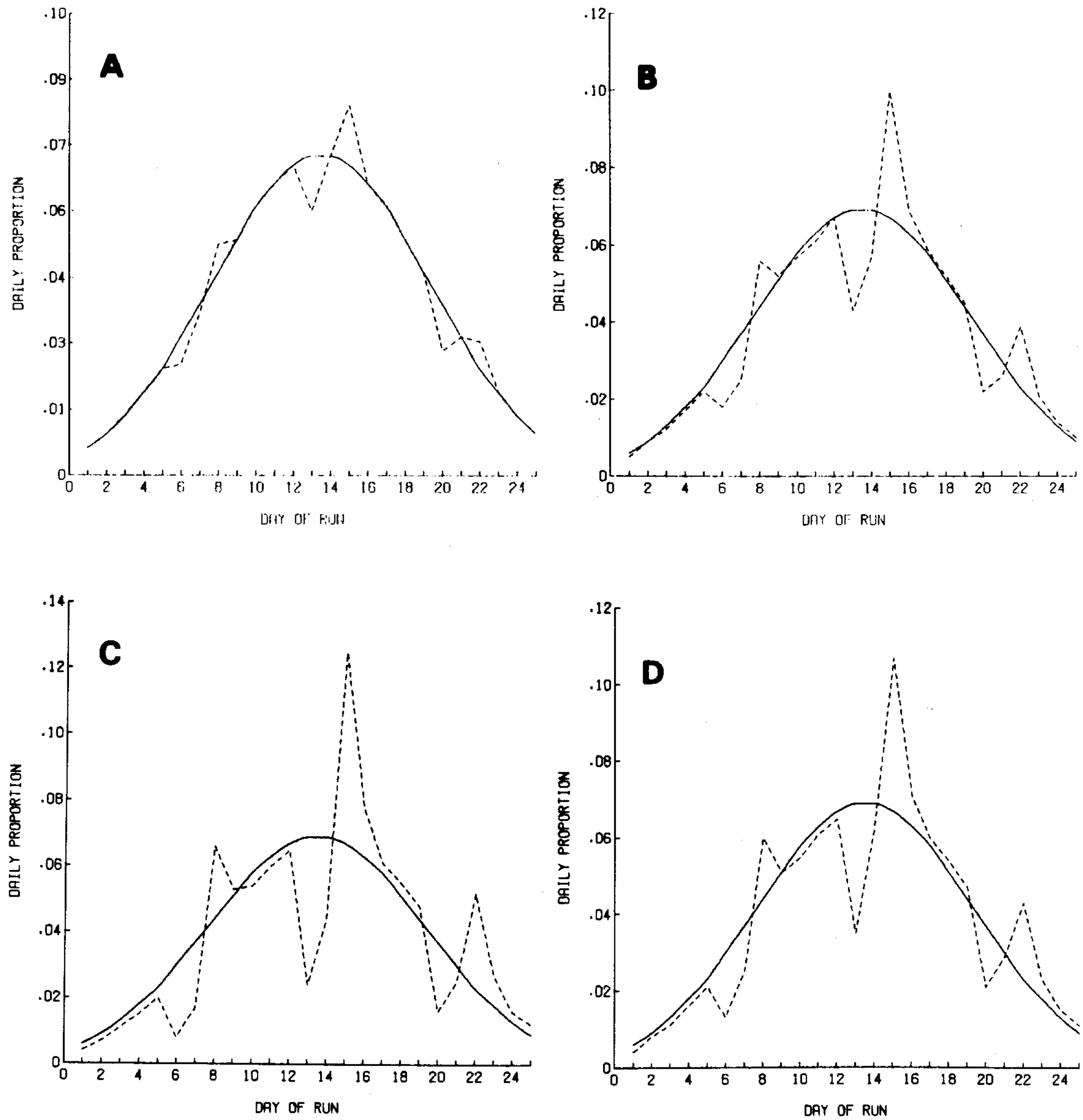


Figure 20. Comparison of the normal pattern of arrival (line) and the entry pattern (dashed) recreated by adding catch plus escapement of a sockeye salmon population with four theorized patterns of departure and a five-day fishing period:

A: Exponential departure where all have departed in two days.

B: Exponential departure where all have departed in four days.

C: Departure pattern, 20% the first, 60% the second, and 20% the third day.

D: Departure pattern, 10% the first, 20% the second, and 70% the third day.

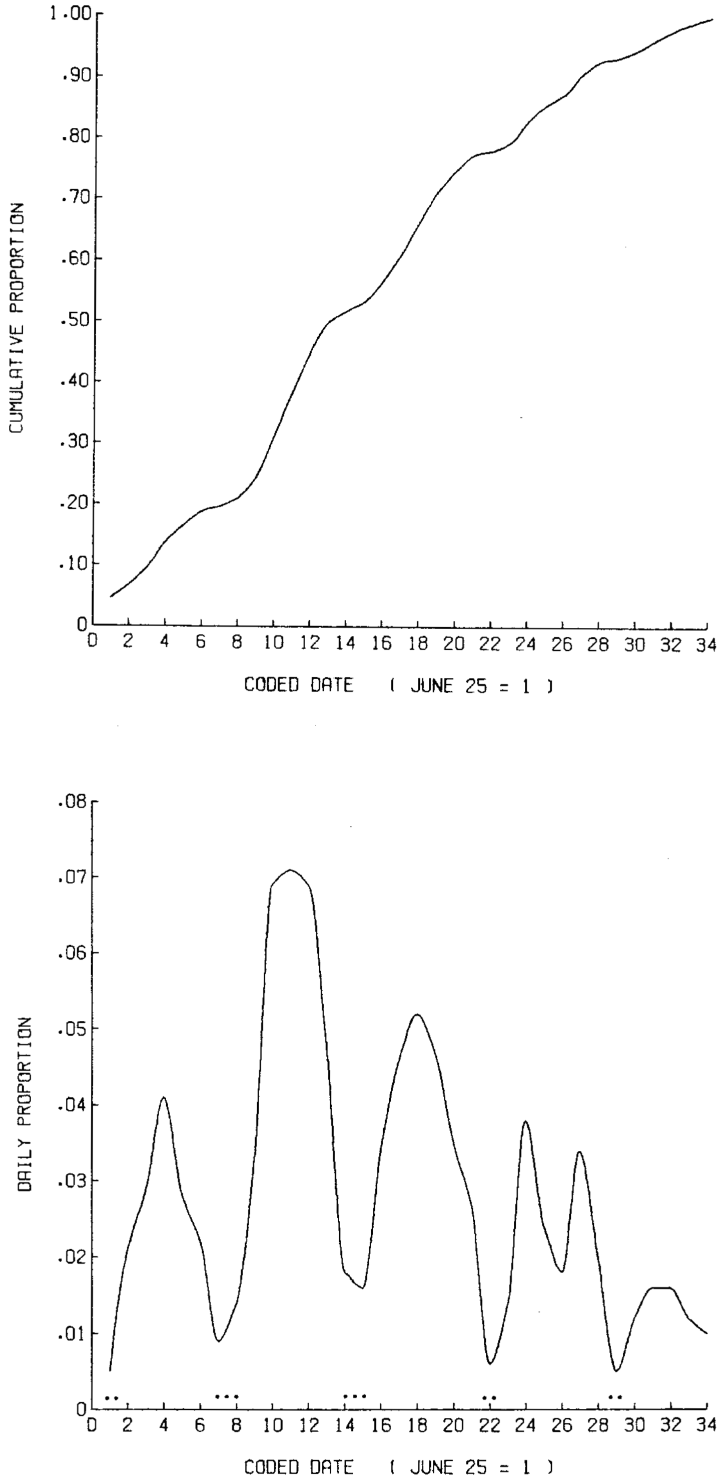


Figure 21. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1978, (...) represents periods closed to fishing.

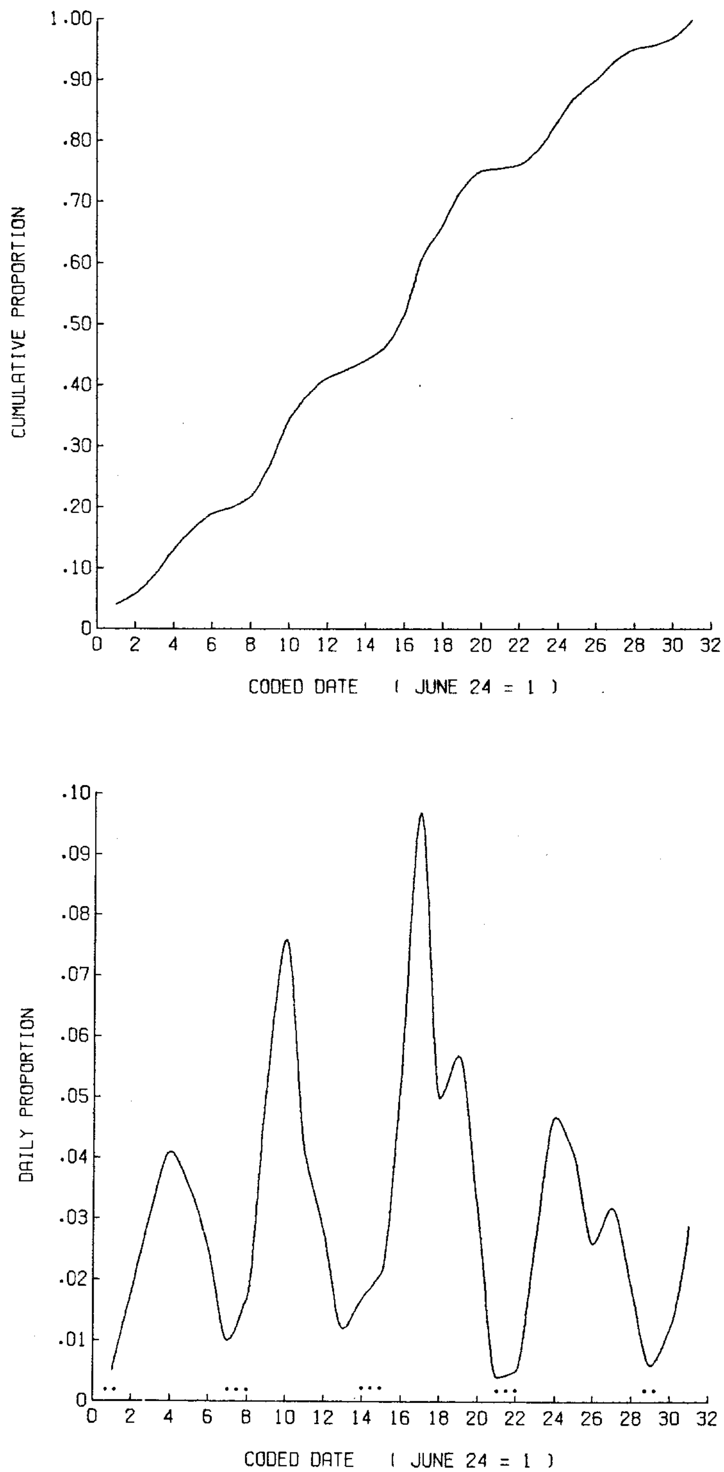


Figure 22. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1979, (...) represents periods closed to fishing.

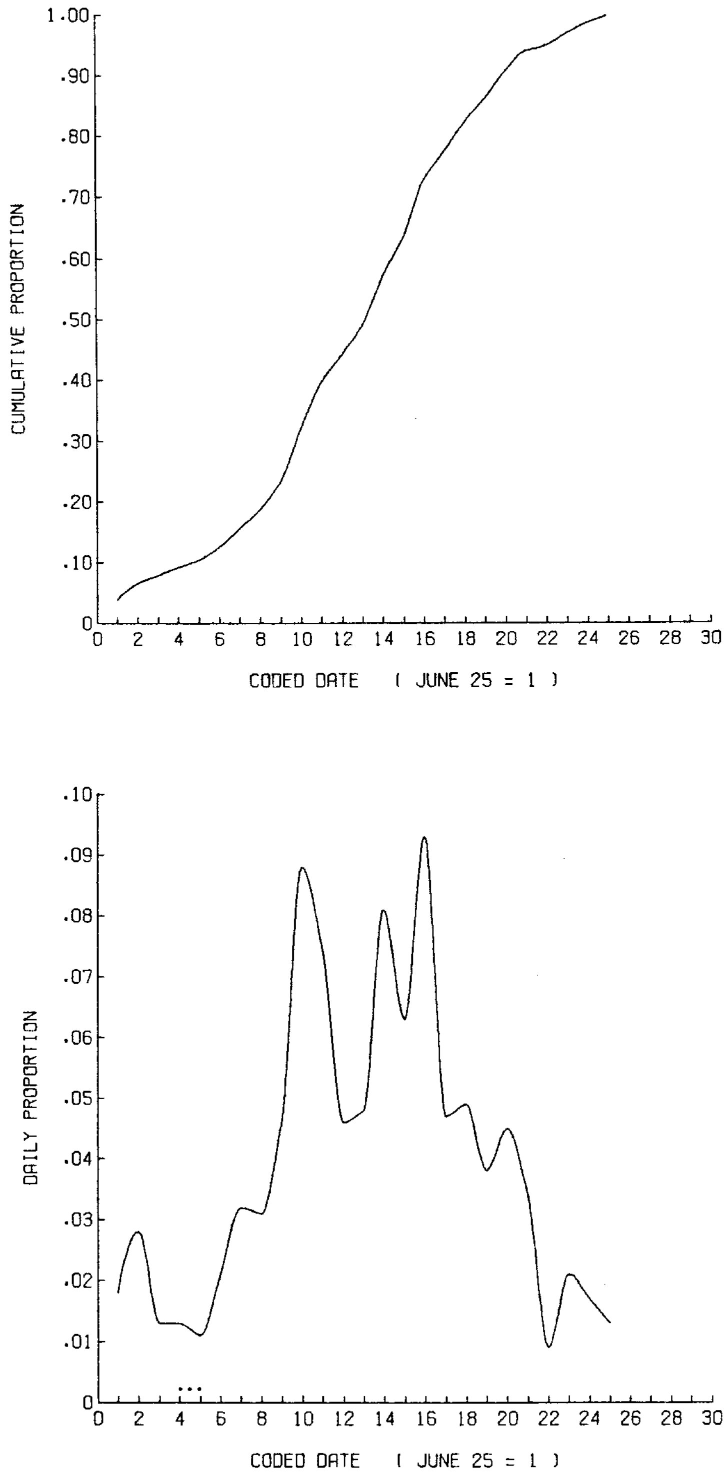


Figure 23. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1980, (...) represents period closed to fishing.

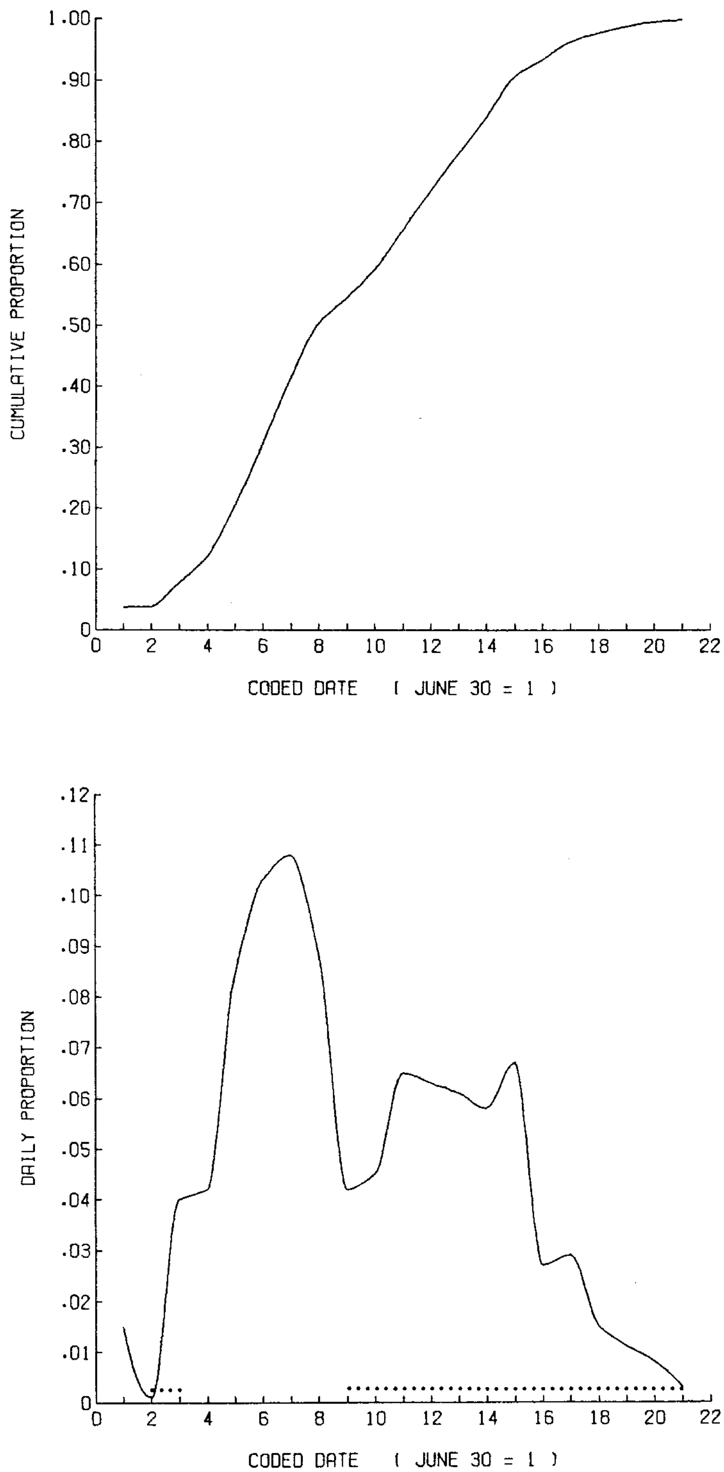


Figure 24. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1972, (...) represents periods closed to fishing.

most likely sees a more true picture of the pattern of arrival and departure. The ideal situation to best view the pattern of arrival would be generated by a season of continuous fishing with constant effort or no fishing at all given a true functional understanding of travel times. The entry pattern as defined in Togiak thus becomes a function of the fishing periods, the arrival, and the departure distribution. The arrival distribution will dictate run initiation, length, and overall shape. The departure distribution then interacts with the pattern of the fishing periods to create troughs during closed periods and spikes on Mondays. How consistent these are will affect the consistency of the entry pattern necessary for development of a migratory time-density function useful in total run estimation.

A migratory time-density function for Togiak Bay sockeye salmon was viewed in the discrete case in that time could take on only non-negative integer values. Thus, a continuous function was not fit to historic data, but rather a historical average across time was developed. To minimize the difference between yearly curves, it was noted that date of run initiation differed by greater than 1 week. Therefore, the average was not made across calendar date but rather by day of run. The dates of a season's entry pattern were then coded where day one occurred when as close to 4% of the run had been accounted for. This allowed for the truncation of the leading tail of the distribution of quite variable length. In addition, the 4% mark often coincided with the maximum rate of increase in daily abundance. Thus allowing run initiation to vary as day one of the run enables the model to incorporate environmental conditions as it influences timing (Burgner 1978).

An average migratory time-density function was then calculated as the historical average for 1967 to 1980 (Table 18 and Figure 25). Day one ranged from 23 June 1968 to 3 July 1971. The entry pattern of 1972 was not incorporated because this year was an anomaly in that it lasted 22 days, was extremely small, and no fishing was allowed after 7 July; greatly affecting its apparent entry pattern. Table 19 presents each season's (j) mean and variance where the mean is calculated as:

$$\bar{t}_j = \sum_{i=1}^{n} t_{ij} f(t_{ij})$$

where:

t_{ij} = the i^{th} day of year j of length n;

$f(t_{ij})$ = proportion of the year's (j) total run observed on day i (t_{ij})

The variance of year j becomes:

$$s^2_j = \sum_{i=1}^{n} (\bar{t}_j - t_{ij})^2 f(t_{ij})$$

To evaluate the stability of the entry pattern through time in relation to the historic average, three levels of each were plotted (Figure 26). By defining day one as the 4% level, the 10% level is quite stable through time. Yet days

Table 18. Cumulative proportion by day of run for Togiak Bay sockeye salmon 1967 to 1980. The resulting mean is the migratory time-density schedule for use in total run estimation.

Day	1967	1968	1969	1971	1973	1974	1975	1976	1977	1978	1979	1980	Mean	Standard deviation
1	0.029	0.034	0.032	0.042	0.038	0.038	0.026	0.034	0.039	0.046	0.040	0.039	0.036	0.0058
2	0.075	0.048	0.048	0.053	0.087	0.051	0.070	0.049	0.055	0.067	0.057	0.066	0.061	0.0124
3	0.108	0.099	0.080	0.078	0.129	0.086	0.092	0.095	0.091	0.096	0.088	0.079	0.094	0.0143
4	0.138	0.161	0.128	0.116	0.175	0.157	0.125	0.141	0.150	0.137	0.129	0.092	0.137	0.0219
5	0.172	0.226	0.181	0.151	0.228	0.212	0.167	0.190	0.210	0.165	0.164	0.103	0.181	0.0355
6	0.178	0.285	0.270	0.211	0.265	0.252	0.235	0.241	0.282	0.188	0.189	0.125	0.227	0.0492
7	0.190	0.297	0.335	0.256	0.310	0.280	0.312	0.268	0.340	0.196	0.199	0.156	0.262	0.0621
8	0.209	0.313	0.397	0.313	0.338	0.321	0.437	0.289	0.374	0.210	0.217	0.187	0.300	0.0809
9	0.314	0.352	0.466	0.357	0.375	0.383	0.482	0.349	0.400	0.244	0.267	0.233	0.352	0.0787
10	0.389	0.418	0.480	0.389	0.437	0.513	0.532	0.420	0.447	0.313	0.343	0.322	0.417	0.0705
11	0.434	0.495	0.519	0.454	0.523	0.586	0.558	0.467	0.516	0.384	0.384	0.396	0.476	0.0678
12	0.506	0.555	0.553	0.524	0.601	0.599	0.576	0.551	0.553	0.452	0.412	0.442	0.527	0.0619
13	0.526	0.622	0.579	0.574	0.640	0.613	0.596	0.621	0.569	0.500	0.425	0.491	0.563	0.0650
14	0.550	0.642	0.635	0.605	0.677	0.636	0.641	0.644	0.591	0.518	0.441	0.571	0.596	0.0668
15	0.575	0.658	0.707	0.625	0.704	0.652	0.711	0.658	0.612	0.534	0.462	0.635	0.628	0.0743
16	0.597	0.673	0.773	0.641	0.724	0.670	0.755	0.669	0.626	0.568	0.515	0.728	0.662	0.0773
17	0.728	0.726	0.792	0.679	0.737	0.741	0.794	0.721	0.673	0.614	0.612	0.775	0.716	0.0611
18	0.811	0.779	0.809	0.733	0.746	0.825	0.834	0.774	0.718	0.666	0.663	0.824	0.766	0.0600
19	0.848	0.787	0.816	0.764	0.764	0.893	0.865	0.834	0.765	0.713	0.720	0.862	0.803	0.0590
20	0.889	0.789	0.830	0.773	0.770	0.949	0.869	0.859	0.812	0.749	0.752	0.907	0.830	0.0650
21	0.926	0.799	0.839	0.800	0.790	0.965	0.888	0.865	0.841	0.776	0.756	0.941	0.849	0.0689
22	0.956	0.810	0.858	0.841	0.797	0.983	0.929	0.874	0.849	0.781	0.761	0.949	0.866	0.0737
23	0.973	0.814	0.867	0.854	0.809	0.995	0.959	0.895	0.852	0.796	0.787	0.970	0.881	0.0758
24	0.983	0.822	0.884	0.875	0.850	0.998	0.981	0.930	0.882	0.833	0.834	0.987	0.905	0.0674
25	0.987	0.832	0.900	0.907	0.901	1.000	1.000	0.972	0.918	0.858	0.875	1.000	0.929	0.0604

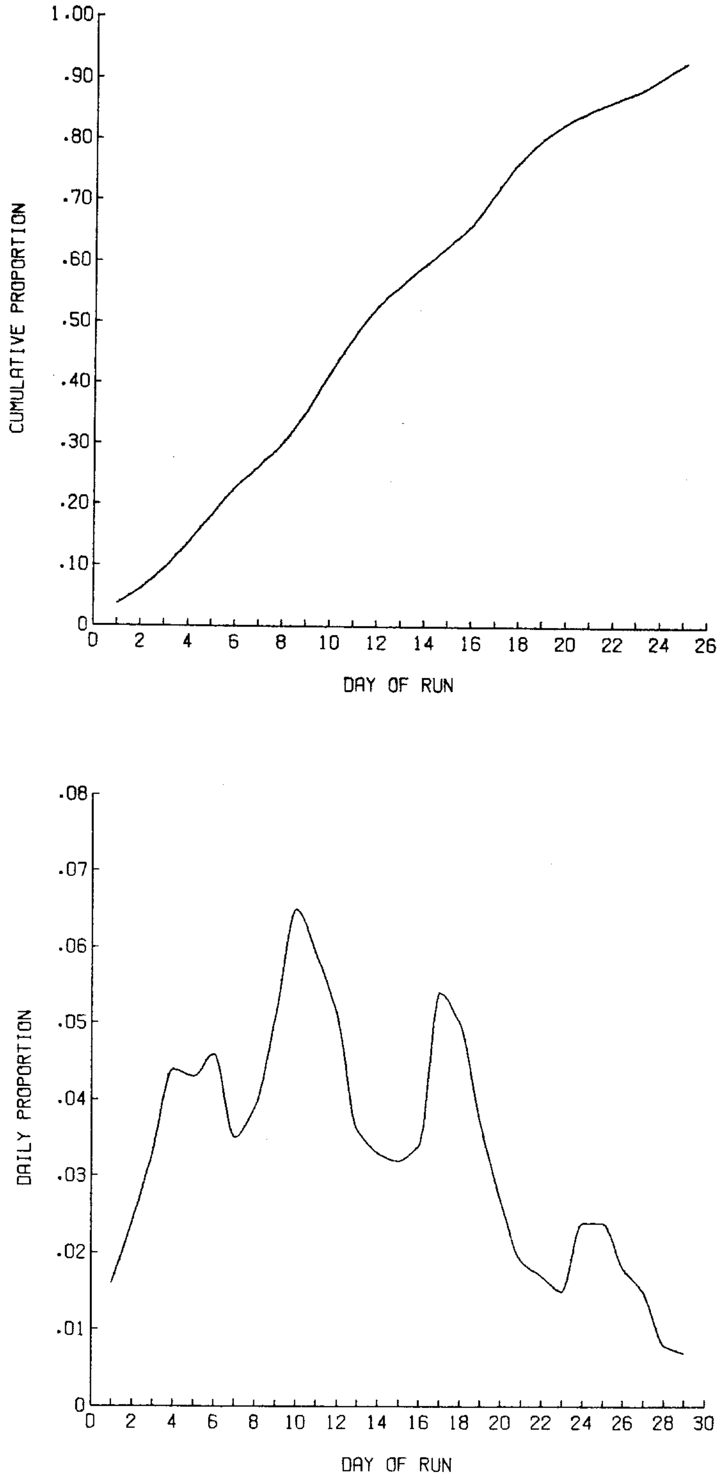


Figure 25. Cumulative (top) and daily (bottom) proportion curves for the historical mean entry pattern of Togiak Bay sockeye salmon run.

Table 19. Statistics of the relative proportion curves of daily abundance for the Togiak Bay sockeye salmon run, 1967 to 1980.

Year	Mean	Date of mean	SD[1]	Variance
1967	12.9	7/08	6.2	39.0
1968	14.7	7/07	10.1	102.7
1969	12.8	7/07	8.2	66.5
1971	14.2	7/16	7.7	59.1
1972	8.5	7/07	3.9	15.5
1973	12.6	7/07	7.9	62.6
1974	11.6	7/04	5.8	33.3
1975	11.6	7/12	6.4	41.4
1976	12.6	7/09	6.7	45.3
1977	12.9	7/07	7.7	59.5
1978	15.0	7/09	8.0	64.6
1979	15.1	7/08	7.7	59.8
1980	13.1	7/07	5.4	29.5
Average[2]	13.1		7.3	52.9

[1]SD = standard deviation.

[2]Historic average includes data from 1972.

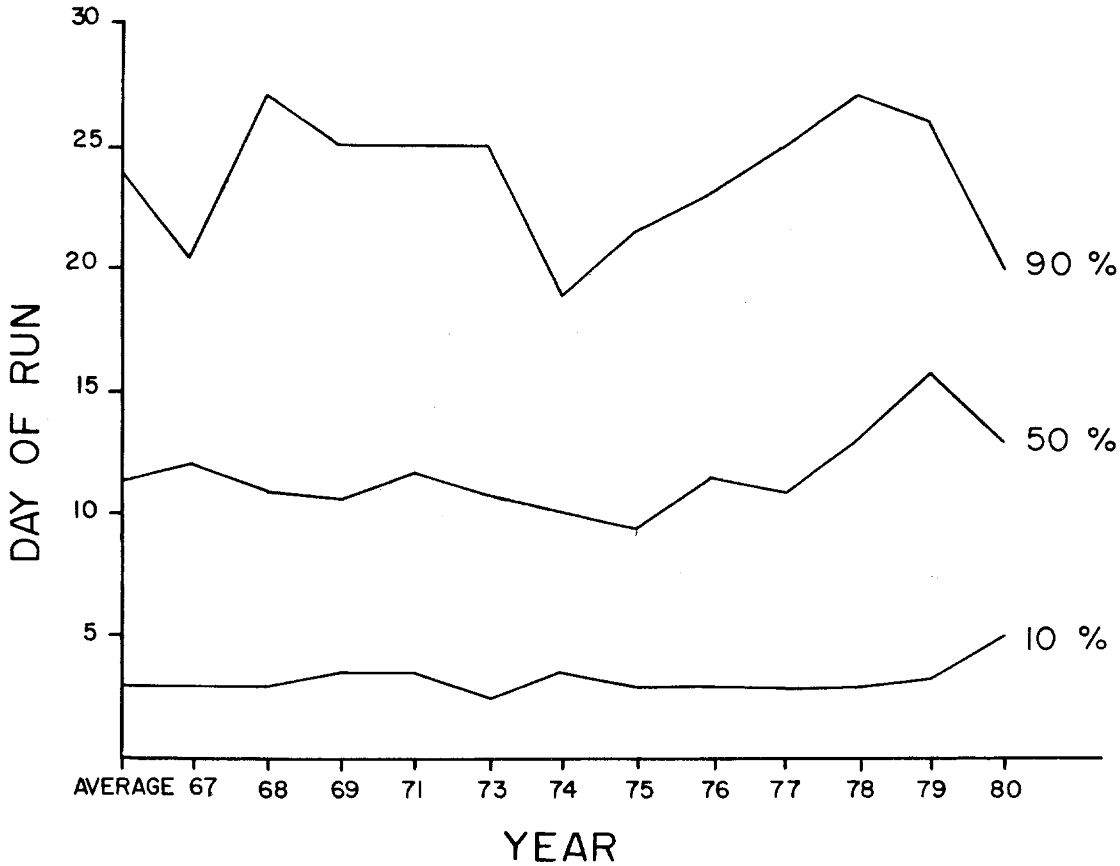


Figure 26. Comparison of three levels of the cumulative proportion curves for the Togiak Bay sockeye salmon run, 1967-1980.

of the 50% and 90% levels occur with increased variability. Overall, the system is stable through 1977 with some trending toward a later mid-point (50%) in 1978-1980. Thus, the historic average cumulative proportion curve can be viewed in relation to the departure of all other years from the average (Figure 27).

A critical point in the in-season application of a migratory time-density function is the detection of day one of the run. Initially, it was defined as the point where 4% of the run is accounted for. This also coincides with the maximum rate of increase early in the season. Criteria were then developed for the in-season choice of day one which most closely matches that of post-season analysis.

Foremost, day one is detected as the maximum rise in catch per landing during the period 15 June-4 July. The rise becomes the difference between 2 days CPUE [CPUE of day (i) - CPUE of day $(i-1)$]. The difference for the first day after a closed period (say for Monday) becomes the difference between that and the last day of the previous fishing period. Secondly, because one doesn't want to wait until July 4th, historically, a good guideline has been shown to be 3.6% of forecast catch. The value 3.6% is the proportion for the historical day one (Table 18). This minimizes the tendency to start too early with a false rise. The 3.6% of forecast catch also distinguishes later rises where a substantial catch has been made. This has worked even in 1978 where forecast was 60% low and in 1969 where forecast was high by 48%. It will not work in years with price disputes where CPUE alone reflects run size. Results of choice of day one from historical data based on the above criteria (Table 20) were always less than 2 days from the choice of post-season analysis. An error of greater than 1 day occurred when day one arose during a closed period for which little can be done with catch data alone.

In summary, the average migratory time-density function (1967-1980) would be used in-season where total run would be estimated as the ratio of observed cumulative abundance to proportion expected. Total run estimates would be made daily and then averaged across time for documentation as total run estimates on a schedule satisfactory to the management agency. The unweighted average across time is proposed to balance the influence of several factors. Initially, it was observed that the variance of a day's expected cumulative proportion from the historic migratory time-density function increases through the eighth day of the run (Table 18). In contrast, the variance of a total run estimate incorporates the reciprocal of the expected cumulative proportion to date which decreases with day of run (see page 78). Finally, it is a statistical fact that the variance of a mean is less than the variances of the independent and identically distributed random variables on which it is based. Here we will assume independent estimates where the variances can be summed. In analysis involving historical data an average across time best estimated total run size.

Variance for the Total Run Estimate

After estimation of total run size based on the migratory time-density function, a variance for the estimate can be calculated in two situations. In the first situation where total run size (N_T) is a function of only one variable $[F_T(t)]$,

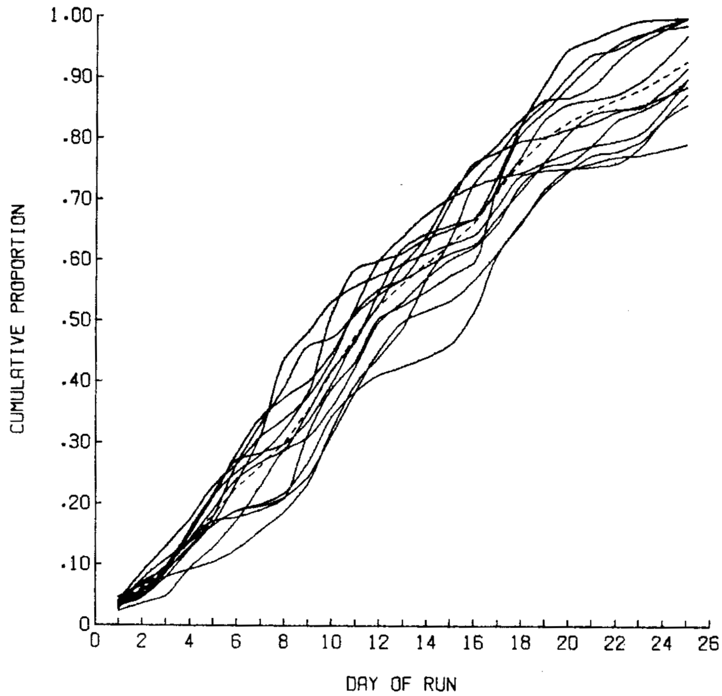


Figure 27. Cumulative proportion curves of the historical mean and the years 1967-1980 of the Togiak Bay sockeye salmon run.

Table 20. Comparison of the choice of day one of the Togiak Bay sockeye salmon run using inseason criteria versus that resulting from post-season analysis.

Year	Post season analysis		In-season detection by defined criteria		Difference in days
1967	6/26	Mon.	6/27	Tues.	1
1968	6/23	Sat.	6/25	Mon.	2
1969	6/26	Thurs	6/25	Wed.	1
1971	7/03	Fri	7/03	Fri.	0
1973	6/25	Mon.	6/26	Tues.	1
1974	6/23	Sat.	6/25	Tues.	2
1975	7/01	Tues.	7/01	Tues.	0
1976	6/27	Sun.	6/28	Mon.	1
1977	6/25	Sat.	6/27	Mon.	2
1978	6/25	Sun.	6/26	Mon.	1
1979	6/24	Sun.	6/25	Mon.	1
1980	6/25	Wed.	6/25	Wed.	0

the expected proportion to date. The variance of total run size for this model was developed by Dr. D.J. Bigelow for Walters and Buckingham (1975) with

$$N_T = \frac{N_t}{F_T(t)} ,$$

where N_t = cumulative run to date (t), as

$$V(N_T) = \frac{N_t^2}{[F_T(t)]^4} \; V[F_T(t)] \left[1 + \frac{2\,V[F_T(t)]}{[F_T(t)]^2} \right] .$$

In Togiak this would occur when total run to date was composed of catch and lagged tower counts of escapement. In addition, a second situation occurs in the Togiak fishery model where the total run estimate is a function of two variables. Here the second variable is the cumulative run to date (N_t) which is now catch plus estimated escapement. Thus, using the delta method with an assumed zero covariance between the two variables:

$$V(N_T) \approx \frac{N_t^2}{[F_T(t)]^4} \; V[F_T(t)] + \frac{V(N_t)}{[F_T(t)]^2}$$

the variance for total run to date becomes the sum of the variances of daily abundance as described in the above section on a Proposed Model to Estimate Daily Abundance.

THE TOGIAK FISHERY MODEL

The objectives of the Togiak fishery model were to estimate daily escapement and total run size in-season for Togiak River sockeye salmon. Given that a system is managed for an escapement goal, here of 100,000 sockeye salmon, fisheries biologists need reliable, up-to-date information on the status of its fulfillment. In Togiak, counting towers are located upriver an average of 11 day's travel time for fish leaving the bay. In-season estimates of escapement have been comprised of the cumulative tower counts and an estimate of fish in the river below the towers based on aerial surveys. A system of this size has not warranted a test fishery so an alternative, or verification, of the aerial survey - tower count combination was proposed instead. In Togiak, the extended fishing periods afforded the use of CPUE to estimate daily escapement. In addition, fishery managers seek verification of the forecast early enough in the season so that any significant divergence can be compensated for in altering fishing time to ensure fulfillment of the escapement goal. In response, total run size was to be estimated throughout the season using a migratory time-density function.

Daily escapement was estimated from CPUE during the fishing periods as discussed under the section on model derivation. The catchability coefficient then becomes a function of effort as demonstrated in the investigation into variance components of catchability (see page 30). During days closed to fishing, typically the weekend, an interpolation function was used (see page 51). Therefore, Saturday's escapement will be estimated from Friday's and Sunday's from Saturday's.

A migratory time-density function will be used in conjunction with the cumulative abundance to date for total run estimation (see above section on Total Run Estimation). A discrete density approach was used in that a historic average over the years 1967-1980 (Table 18) was developed. The run was defined to begin when 3.6% of the total abundance is accounted for, based on the development of historic runs from catch plus escapement. In-season day one is detected from change in CPUE and the level of catch. The run to date is then accumulated over the time for which fish are observed by the counting towers with an appropriate lag and representing an average 3.6%. For illustration, assume day one was determined to be 25 June based on catch and effort data. Following that, fish were first observed passing the tower 30 June but under a thousand per day. On 5 July several thousand passed and by 7 July it became apparent that the run had begun passing the tower with a 10-day lag. One could then assume the fish passing the towers 30 July to 5 July were present in Togiak Bay 20 to 25 June. Catch would then be accumulated over that period with the appropriately lagged escapement for a run to date for day one of 25 June. Yet one does not want to wait until 7 July to begin total run estimation as daily abundance is available from CPUE data after 25 June. An alternative migratory time-density function was developed for use after day one has been defined, until such time that tower counts become available with an estimated lag time. Here, there has not been an accumulation over past catches but rather, accumulation begins on day one (Table 21). Again, it is a discrete density as an average across day of the run (1967-1980). Note, day one now occurs when 2% of the run is expected but otherwise parallels the unadjusted historic average. Total run size is thus calculated each day as run to date over expected proportion based on the appropriate migratory time-density schedule. Total run estimates were made available to fisheries biologists as the averages across time to points along the run (10, 25, 50, 75%).

In-season the information flow will follow closely that of Figure 28. Beginning mid-June total catch and the number of landings will be collected daily via radio by the ADF&G sampler stationed at Togiak Cannery. The data will then be compiled and radioed to the area management biologist in Dillingham. A CPUE will be calculated as catch per daily landing from these data. Initially the daily change in CPUE will be monitored for detection of day one in late June. Upon detection, estimation of daily abundance, escapement, and total run size will begin. Thereafter, upon reception of the day's catch and effort statistics, catchability (q) will be calculated as a function of effort. Three functions relating catchability to effort by week are being evaluated the first season; those being a linear model (Table 22), a power curve model (Table 23) and an exponential model (Table 24). Daily abundance (N_1) is then calculated from the CPUE and catchability estimate and is reported as a daily and cumulative estimate. Lastly, escapement (E) becomes the difference between daily abundance and catch. It is also reported as a daily and cumulative estimate

Table 21. Adjusted migratory time-density function for Togiak Bay sockeye salmon based on data of 1967 to 1980.

Day of run	Expected cumulative proportion	Standard deviation
1	0.0195	0.004
2	0.056	0.013
3	0.099	0.022
4	0.135	0.027
5	0.186	0.038
6	0.221	0.044
7	0.257	0.058
8	0.322	0.094
9	0.385	0.087
10	0.439	0.079
11	0.496	0.073
12	0.548	0.075
13	0.573	0.077
14	0.603	0.086
15	0.644	0.095
16	0.688	0.098
17	0.738	0.091
18	0.781	0.081
19	0.795	0.079
20	0.828	0.076
21	0.843	0.077
22	0.863	0.077
23	0.884	0.073
24	0.912	0.063
25	0.937	0.053

TOGIAK BAY SOCKEYE ESTIMATION PROCESS

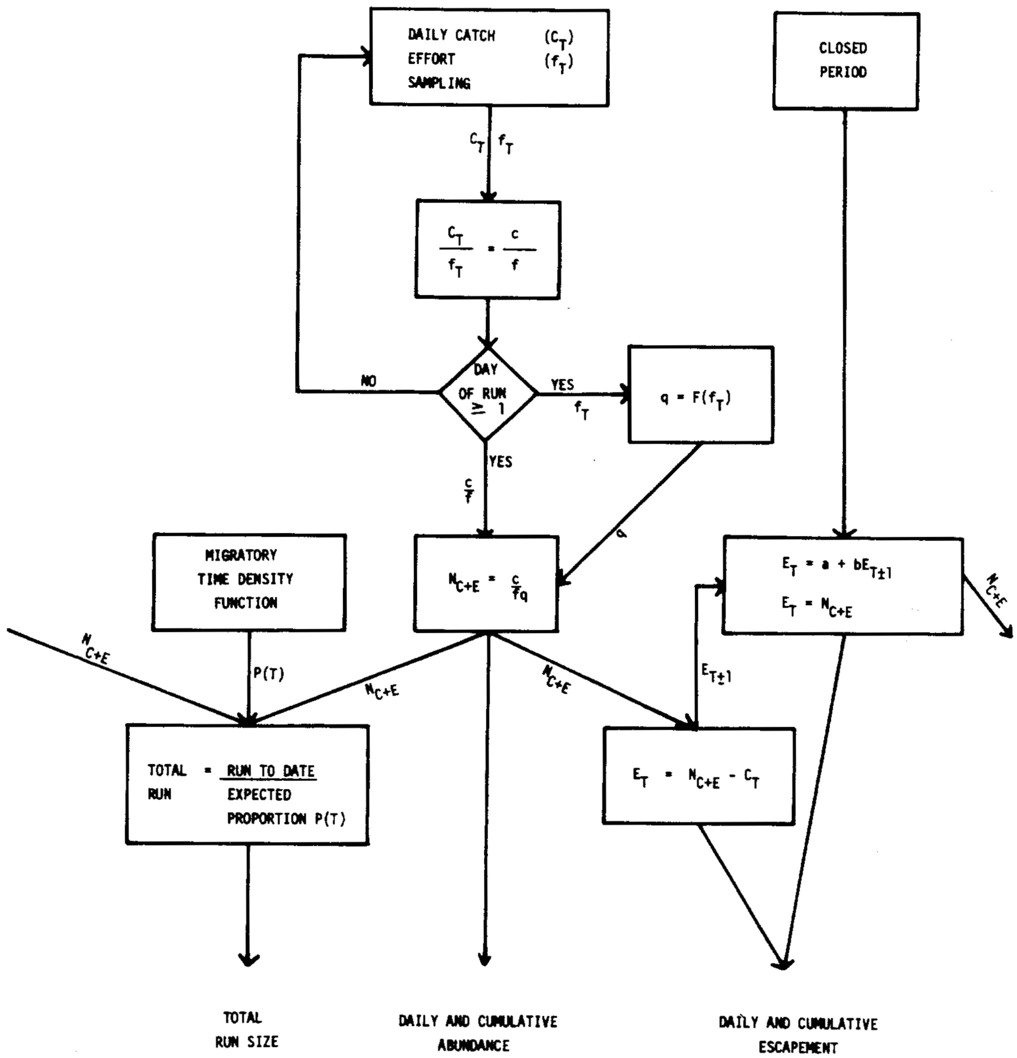


Figure 28. Information flow for the Togiak Bay sockeye salmon model.

Table 22. Statistics of the linear model for daily catchability (q) as a function of effort (f) for the Togiak Bay sockeye salmon fishery.

Regression equation: $q = a + bf$

Parameter estimates A	B	R^2	SD	n	Period of validity
9.619×10^{-3}	-3.514×10^{-5}	0.67	1.00×10^{-3}	18	First weekly fishing period which includes day 1 of run
1.382×10^{-2}	-6.190×10^{-5}	0.75	1.65×10^{-3}	22	Second week
1.397×10^{-2}	-5.396×10^{-5}	0.79	1.54×10^{-3}	26	Third week
1.394×10^{-2}	-5.597×10^{-5}	0.82	1.23×10^{-3}	25	Fourth week and thereafter

Where:
q = Catchability coefficient
f = Effort in landings per day
a,b = Model coefficients
R^2 = Coefficient of determination
SD = Standard deviation
n = Sample size

Table 23. Statistics of the power curve model for daily catchability (q) as a function of effort (f) for the Togiak Bay sockeye salmon fishery.

Regression equation: $q = af^b$

Parameter estimates

A	B	R^2	n [1]	Period of validity
1.784×10^{-1}	-7.499×10^{-1}	0.70 [2]	18	First weekly fishing period which includes day 1 of run
3.535×10^{-1}	-8.713×10^{-1}	0.81	22	Second week
1.744×10^{-1}	-6.946×10^{-1}	0.83	26	Third week
2.026×10^{-1}	-7.211×10^{-1}	0.80	25	Fourth week and thereafter

Where: q = Catchability coefficient
f = Effort in landings per day
a,b = Model coefficients
R^2 = Coefficient of determination
n = Sample size

1 Standard deviation is not presented as data were transformed for a linear regression.

2 A SPSS NON-LINEAR program was used in Chapter 2 thus R^2 values may differ.

Table 24. Statistics of the negative exponential model for daily catchability (q) as a function of effort (f) for the Togiak Bay sockeye salmon fishery.

Regression equation: $q = a \exp(bf)$

Parameter estimates A	B	R^2	n[1]	Period of validity
1.15×10^{-2}	-6.730×10^{-3}	0.70 [2]	18	First weekly fishing period which includes day 1 of run
1.66×10^{-2}	-8.723×10^{-3}	0.78	22	Second week
1.64×10^{-2}	-7.269×10^{-3}	0.88	26	Third week
1.56×10^{-2}	-7.092×10^{-3}	0.84	25	Fourth week and thereafter

Where: q = Catchability coefficient
f = Effort in landings per day
a,b = Model coefficients
R^2 = Coefficient of determination
n = Sample size

1 Standard deviation is not presented as data were transformed for a linear regression.

2 A SPSS NON-LINEAR program was used in Chapter 2 thus R^2 values may differ.

for use by managers to judge fulfillment of the escapement goal. During closed periods an interpolation function will be used to estimate daily escapement and abundance where in this instance the two are equal.

In addition to escapement estimation, cumulative abundance will be used with the appropriate migratory time-density function to estimate total run size each day. These estimates will be averaged across time with a resulting estimate documented on days 3, 7, 11, and 17 of the run when 10, 25, 50, and 75% of the total is accounted for. As tower counts with an appropriate lag time become available these will replace the estimated escapement in the accumulative run to date thus eliminating a variance component in the total run estimate, and the total run size will again be estimated for days 3, 7, and 11 of the run.

IN-SEASON USE OF THE TOGIAK FISHERY MODEL

Escapement Estimation

In the 1981 season, use of the Togiak fishery model began with the detection of day one of the run. Daily collection of data in Togiak began on 22 June allowing the monitoring of the change in CPUE (Table 25). The forecast was for a harvest of 547,000 sockeye salmon. This meant day one representing 3.6% of the run would have a cumulative catch of 20,000 sockeye salmon forming one criterion for choice of run initiation. Another criterion for day one is that it have the maximum daily change in catch per landing (CPUE) for the period 15 June to 4 July. One July resulted in the maximum change in CPUE (Table 25), but cumulative catch at that point was 39,336, almost double the forecast of 20,000 for day one. The next largest change in CPUE occurring prior to that was on 30 June with a cumulative catch much closer to forecast (25,454). Thus, day one was defined to be 30 June until tower counts could provide additional information. Escapement estimation began for the first week's fishing period on 29 June. The 1981 run appeared late when compared with the historical (1967-1980) average run initiation of 27 June.

Fish were first sighted passing the counting towers on 4 July with the subsequent 24-hour count beginning that noon. Soon there appeared to be a 10 or 11 day lag, both of which were used for in-season documentation. In viewing the season's daily and cumulative escapement estimates (Table 26 and 27) it becomes apparent that the models describing catchability as a function of effort behaved quite differently. The linear relationship was not useful, especially in the extrapolation necessary for the large level of effort observed in 1981 beyond that on which the regression was based. The exponential model had a lower overall percent error in relation to the tower counts but again its behavior in the tail was not satisfactory for large effort. As found in its development (see above Proposed Model to Estimate Daily Abudance), the power curve had the overall best fit and was the preferred model whose estimates were subsequently reported to the management biologist. When comparing tower counts in the time period for which escapement estimates are available, the percent error with the power curve model was 2% and when adding escapement prior to 29 June the difference becomes 11.6%. After 1 July, the percent error in the cumulative

Table 25. Catch and effort statistics for the 1981 Togiak River sockeye salmon run.

Date	Sockeye catch	Landings	CPUE	Change in CPUE	Cumulative catch
6/22	245	23	10.7	+10.7	1,404
23	2,949	171	17.2	+ 6.5	4,353
24	3,746	119	31.5	+14.3	8,099
25	4,053	142	28.5	- 3.0	12,152
26	3,694	127	29.1	+ 0.6	15,846
27	Closed to fishing				
28	" " " "				
29	1,363	45	30.3	+ 1.2	17,209
30	8,245	165	50.0	+19.7	25,454
7/01	13,882	169	82.1	+32.1	39,336
02	12,983	156	83.2	+ 1.1	52,319
03	8,526	102	83.6	+ 0.4	60,845
04	Closed to fishing				

Table 26. Comparison of daily escapement of the Togiak River sockeye salmon run from tower counts and estimates using CPUE of the commercial fishery with three different relationships. An 11 day lag is assumed.

Date of escapement	Date pass towers	Daily tower counts	Escapement estimated from CPUE					
			Linear model	% error	Exponential model	% error	Power curve model	% error
6/23	7/04	786						
24	05	684						
25	06	1,776						
26	07	3,276						
27	08	8,376						
28	09	12,756						
29	10	9,342	2,405	-74	2,202	-76	1,585	-83
30	11	6,456	4,833	-25	4,946	-23	4,640	-28
7/01	12	6,060	8,437	39	8,393	39	7,683	27
02	13	4,338	7,133	64	7,695	77	7,593	75
03	14	5,010	5,325	6	5,914	18	6,502	30
04	15	5,202	4,959	- 5	5,431	4	5,902	13
05	16	7,824	5,232	-33	7,671	- 2	9,904	27
06	17	13,044	4,689	-64	6,744	-48	8,624	-34
07	18	12,378	936,548	7466	26,148	111	12,340	0
08	19	7,920	25,877	227	15,039	90	11,238	42
09	20	6,018	17,814	196	13,576	126	11,496	91
10	21	7,374	12,437	69	13,062	77	13,137	78
11	22	7,038	29,344	317	17,913	155	13,673	94
12	23	8,358	8,830	6	8,469	1	7,890	- 6
13	24	8,100	4,493	-45	6,373	-21	9,577	18
14	25	7,872	14,388	83	10,019	27	5,844	-26
15	26	10,080	11,710	16	9,310	- 8	6,144	-39
16	27	7,704	16,239	111	8,428	9	3,704	-52
17	28	5,418	4,697	-13	4,651	-14	3,729	-31
18	29	7,854	18,760	139	8,235	5	3,083	-61
19	30	6,048	6,558	8	7,339	21	6,807	13
20	31	5,928	3,628	-39	5,930	0	7,048	19
21	8/01	6,780	6,964	3	5,596	-17	3,916	-42
22	02	2,952	31,025	951	9,867	234	3,234	10
23	03	2,040	105,458	5069	12,967	536	2,413	18
24	04	2,112	3,750	78	3,711	76	3,035	44
25	05	1,176	1,782	1/	2,633		3,151	

1/ Counting at towers ended at 6:00 AM and thus not comparable with escapement estimated from CPUE.

Table 27. Comparison of cumulative escapements of the Togiak River sockeye salmon run from tower counts and estimates using CPUE of the commercial fishery with three different relationships. An 11 day lag is assumed.

Date of escapement	Date pass towers	Daily tower counts	Escapement estimated from CPUE: Linear model	% error	Exponential model	% error	Power curve model	% error
29	10	9,342	2,405	-74	2,202	-76	1,585	-83
30	11	15,798[1]	7,238	-54	7,148	-55	6,225	-61
7/01	12	21,858	15,675	-28	15,541	-29	13,908	-36
02	13	26,196	22,809	-13	23,236	-11	21,502	-18
03	14	31,206	28,134	-10	29,151	- 7	28,004	-10
04	15	36,408	33,093	- 9	34,581	- 5	33,906	- 7
05	16	44,232	38,324	-13	42,252	- 4	43,809	- 1
06	17	57,276	43,013	-25	48,996	-14	52,433	- 8
07	18	69,654	979,561	1306	75,144	8	64,773	- 7
08	19	77,574	1,005,438	1196	90,182	16	76,011	- 2
09	20	83,592	1,023,252	1124	103,758	24	87,507	5
10	21	90,966	1,035,689	1039	116,820	28	100,644	11
11	22	98,004	1,065,033	987	134,733	37	114,317	17
12	23	106,362	1,073,863	909	143,202	35	122,207	15
13	24	114,462	1,078,356	842	149,575	31	131,784	15
14	25	122,334	1,092,744	793	159,594	30	137,628	13
15	26	132,414	1,104,454	734	168,904	28	143,772	9
16	27	140,118	1,120,693	700	177,332	27	147,476	5
17	28	145,536	1,125,390	673	181,983	25	151,205	4
18	29	153,390	1,144,149	646	190,218	24	154,288	1
19	30	159,438	1,150,708	622	197,557	24	161,095	1
20	31	165,366	1,154,336	598	203,487	23	168,144	2
21	8/01	172,146	1,161,300	575	209,083	21	172,060	0
22	02	175,098	1,192,325	581	218,950	25	175,294	0
23	03	177,138	1,297,784	633	231,917	31	177,707	0
24	04	179,250	1,301,534	626	235,628	31	180,742	1
25	05	180,426	1,303,315	622	238,261	32	183,893	2
FINAL COUNT		208,080[2]	1,303,315	526	238,261	15	183,893	-12

1 Does not include tower counts from July 4 to 9 for which there was no estimate of escapement from CPUE due to tail truncation and the closed period of 6/27 -28 with resulting tower counts on 7/8-9.

2 Includes the 27,654 sockeye for which no estimates from CPUE were made as indicated in 1/.

escapement estimates based on the power curve were less than 18% though the error in the daily estimates was as great as 94%. All subsequent analysis or reference to estimates from CPUE will refer to those of the power curve model (Table 28) unless otherwise specified.

When escapement estimates are plotted with tower counts lagged back to the date of their probable departure from the bay (Figure 29), the cumulative estimates follow the tower counts quite closely. In contrast, the daily estimates differed substantially at times from the tower counts. Confidence limits at the 95% level were calculated about daily abundance and escapement estimates (Table 29) for an idea of the variability. Due to the nature of the abundance estimate the confidence limits are not symmetrical (see above Proposed Model to Estimate Daily Abundance). In addition, all variability is then transferred to the escapement estimate, for none is associated with the catch.

Techniques used in model development were again used in the post-season analysis of the 1981 daily abundance and escapement estimates. Ultimately 1981 data would be incorporated into the historical data base and new catchability relationships developed for use in 1982. The minimization of the variance in catchability was used as the criterion for the choice of a lag time (see above Model to Estimate Daily Abundance). This resulted in an 11-day lag for 1981. Again, a plot of the proportioned escapement curve (tower counts), catch curve, and CPUE curve (Figure 30) showed a range of 9 to 7 days between the 10% level of the adjusted and unadjusted catch curves with that of the tower counts.

With the lag time determined, observed daily abundance (N_i) can be constructed for 1981 as catch (C_i) plus lagged (L) escapement (E_{i+L}). Catchability (q_i) is then calculated as:

$$q_i = \frac{C_i}{f_i(C_i+E_{i+L})}$$

(see above Model to Estimate Daily Abundance). When these estimates are viewed by week in relation to their respective effort level (f_i) one can evaluate how well the relationship based on historic data predicted the present year (Figure 31). The first day of week one appears to be the only outlier from the historical relationships. It will receive closer inspection before inclusion into the historical data set as it would have a disproportionately large influence on the shape of the curve.

Total Run Estimation

In-season estimation of total run size involves use of the appropriate migratory time-density function (Tables 18 and 21). Estimates were documented in-season as 10, 25, 50, and 75% of the run was accountable. Initially, day one of the run was determined to be 30 June and a total run size was calculated each day thereafter using the migratory time-density function (Table 21) where day one begins the cumulation. Total run estimates were made available to the area management biologist on day 3, 7, 11, and 17 of the run as an average across respective days (Table 30). In viewing the error one must remember that the migratory time-density function is based on a run built up from daily catch and

Table 28. Abundance estimates based on catch and effort data from the Togiak power curve fishery model in 1981.

Date	Daily effort	Daily catch	Daily escapement	Cumulative escapement	Daily abundance	Cumulative abundance
Cum to:						
6/26		15,846				15,846
29	45	1,363	1,585	1,585	2,948	18,794
30	165	8,245	4,640	6,225	12,885	31,679
7/01	169	13,882	7,683	13,908	21,565	53,244
02	156	12,983	7,593	21,502	20,576	73,821
03	102	8,526	6,502	28,004	15,028	88,849
04	Closed to fishing		5,902	33,906	5,902	94,751
05	" " " "	"	9,904	43,809	9,904	104,654
06	104	15,503	8,624	52,433	24,127	128,781
07	221	29,924	12,340	64,773	42,264	171,045
08	179	24,906	11,238	76,011	36,144	207,189
09	167	24,764	11,496	87,507	36,260	243,449
10	149	27,038	13,137	100,644	40,175	283,624
11	177	30,162	13,673	114,317	43,835	327,459
12	47	10,257	7,890	122,207	18,147	345,606
13	92	21,709	9,577	131,784	31,286	376,892
14	188	36,850	5,844	137,628	42,694	419,586
15	182	36,120	6,144	143,772	42,264	461,850
16	201	27,406	3,704	147,476	31,110	492,960
17	172	19,576	3,729	151,205	23,305	516,265
18	208	24,993	3,083	154,288	28,076	544,341
19	62	12,133	6,807	161,095	18,940	563,281
20	120	23,615	7,048	168,144	30,663	593,945
21	169	21,731	3,916	172,060	25,647	619,592
22	208	28,414	3,234	175,294	31,648	651,240
23	232	30,014	2,413	177,707	32,427	683,667
24	159	15,140	3,035	180,742	18,175	701,842
25	96	8,251	3,151	183,893	11,402	713,244

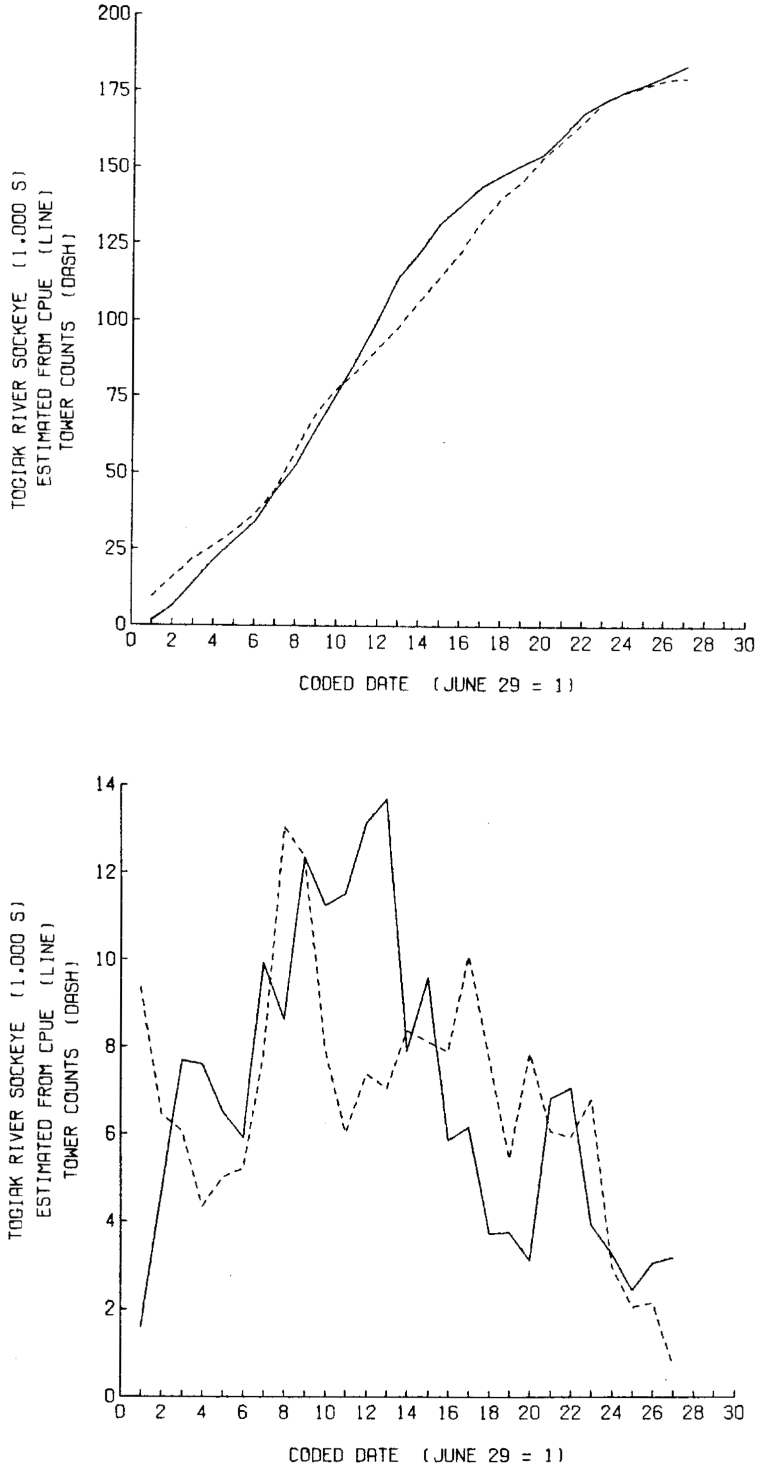


Figure 29. Comparison of cumulative (top) and daily (bottom) escapement of Togiak River sockeye salmon from tower counts and estimates using CPUE of the commercial fishery. An 11-day lag is assumed.

Table 29. Confidence intervals for daily abundance and escapement estimates for the Togiak power curve fishery model in 1981.

Date	Daily abundance	95% Confidence limits		Daily escapement	95% Confidence limits	
		Lower	Upper		Lower	Upper
6/29	2,948	1,912	4,548	1,585	549	3,185
30	12,885	8,742	18,992	4,640	497	10,747
7/01	21,565	14,608	31,838	7,683	726	17,956
02	20,576	14,008	30,219	7,593	1,025	17,236
03	15,028	10,336	21,847	6,502	1,810	13,321
04	5,902	2,702	9,102	5,902	2,702	9,102
05	9,904	4,719	15,089	9,904	4,719	15,089
06	24,127	16,258	35,799	8,624	755	20,296
07	42,264	27,780	64,416	12,340	0	34,492
08	36,144	24,035	54,351	11,238	0	29,445
09	36,260	24,186	54,357	11,496	0	29,593
10	40,175	26,907	59,988	13,137	0	32,950
11	43,835	29,164	65,895	13,673	0	35,733
12	18,147	12,448	26,456	7,890	2,191	16,199
13	31,286	21,760	44,980	9,577	51	23,271
14	42,694	29,488	61,814	5,844	0	24,964
15	42,264	29,215	61,140	6,144	0	25,020
16	31,110	21,452	45,119	3,704	0	17,713
17	23,305	16,130	33,673	3,729	0	14,097
18	28,076	19,340	40,759	3,083	0	15,766
19	18,940	13,769	26,054	6,807	1,636	13,921
20	30,663	22,503	41,782	7,048	0	18,167
21	25,647	18,714	35,152	3,916	0	13,421
22	31,648	22,947	43,672	3,234	0	15,258
23	32,427	23,394	44,952	2,413	0	14,938
24	18,175	13,282	24,875	3,035	0	9,735
25	11,402	8,365	15,539	3,151	114	7,288

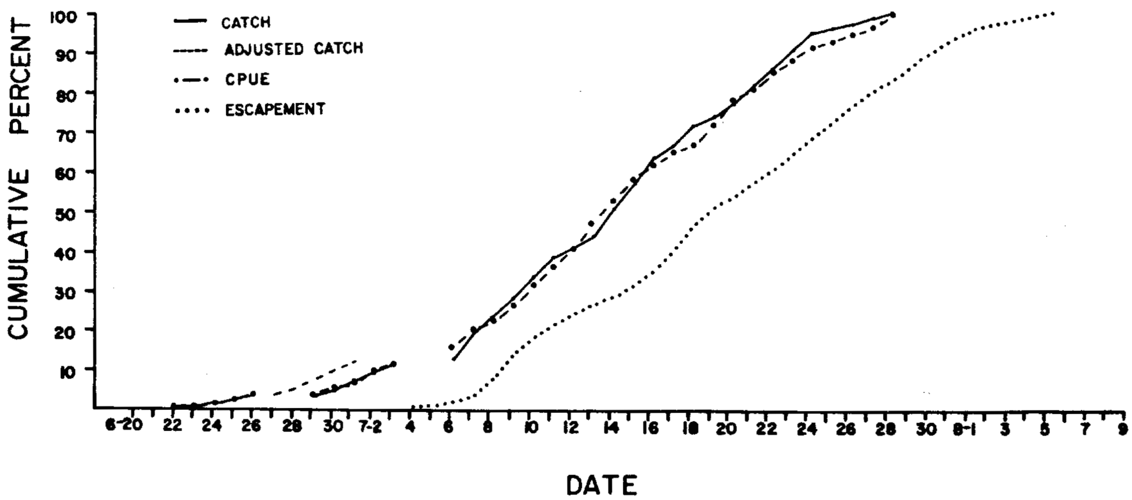


Figure 30. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery in 1981.

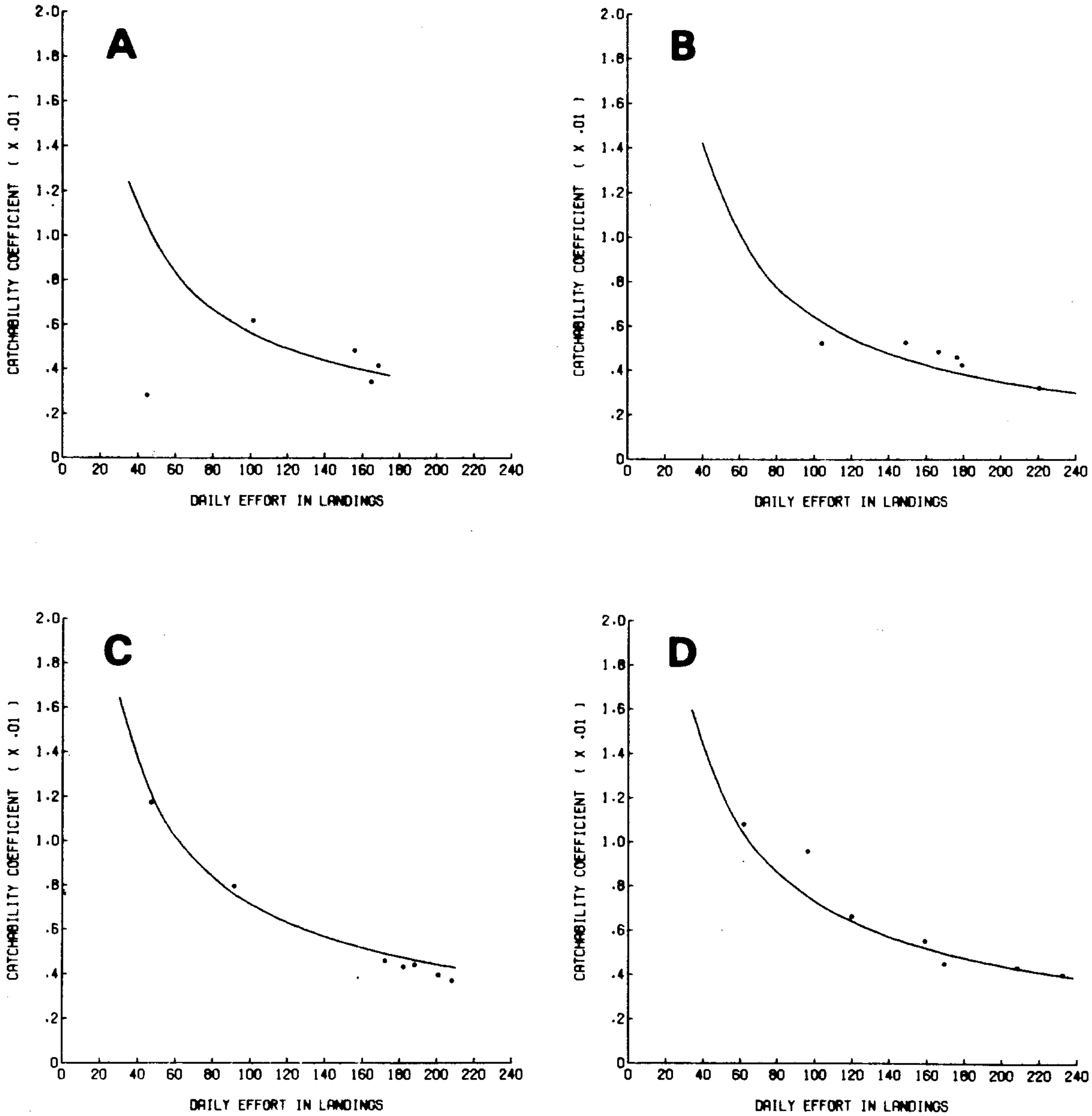


Figure 31. Comparison by week of catchability estimated as a function of effort for the Togiak Bay sockeye salmon fishery (power curve) and that observed in relation to daily abundance present in 1981. Week one (A), week two (B), week three (C), and week four (D).

Table 30. Total run estimates for the Togiak River sockeye salmon run of 1981.

Day of run	Date estimate made	Expected cumulative proportion	Average total run estimate	% Error
3[1]	7/02	0.099	638,000	-13
7	7/06	0.257	515,000	-30
11	7/10	0.496	516,000	-30
17	7/16	0.738	608,000	-17
3[2]	7/10	0.094	689,000	- 6
7	7/14	0.262	566,000	-23
11	7/18	0.476	504,000	-32

[1]From the migratory time density function involving no accumulation prior to day one and using daily abundance estimated from CPUE of the commercial fishery updated with tower counts when available.

[2]From the migratory time density function accumulated over tower counts and using daily abundance calculated from catch and tower counts only.

escapement. Thus, it ends when the tower closes (as lagged back to the time of last departure from Togiak Bay) which in 1981 resulted in a run size of 735,000 ending on 25 July as related to tower closure 11 days later on 5 August.

When tower counts became available after 4 July, it was apparent with an 11-day lag that escapement was substantial during the weekend closure prior to 30 June. The appearance of some 21,000 sockeye salmon suggested that run initiation be pushed back to 27 June, the day on which 8,000 sockeye salmon are theorized to have escaped from Togiak Bay. Estimation of total run could then be made based on the migratory time-density function from the historic average (Table 18) with day one being 4% of the cumulative run. For 1981, the run on day one became the accumulation of catches back to 23 June corresponding to the initial tower count of 4 July lagged back 11 days. Estimates of total run could again be made for the same days of the run but where tower counts replace estimated escapement eliminating a variance component. In averaging across many years day one was forced to be 4% with the result that variability in the migratory time-density function increases with day or run through the eighth day (Figure 25, Table 18). Estimates made early in the run would incorporate a lower variance of proportion expected. This is borne out in viewing the lowest percent error of the 1981 estimates as the estimate made on day three using tower counts (Table 30) followed by the day three estimate using escapement estimates.

With post-season analysis determining the lag time to be 11 days, the observed entry pattern could be reconstructed. Daily and cumulative proportions revealed day one to be 27 June where exactly 4% of the run was accounted for. Again, one sees the troughs created by the closed periods early in the season (Figure 32). When comparing the cumulative proportions of the 1981 season with the historic average comprising the migratory time-density function (Figure 32), it becomes evident why the total run estimates were consistently low. The 1981 run built very slowly through the first 9 days of the run and the expected cumulative proportions used in total run estimation were consistently larger than the actual, giving the appearance of a much smaller run than that present.

Tagging for Riverine Travel Time

The objective in tagging sockeye salmon in Togiak River was to observe the time necessary for fish to travel from the river mouth past the counting towers. Fish were captured from a skiff in the lower reaches of the Togiak River with 10 fathoms of 5-3/8 in (13.2 cm) mesh gill net. Engineer's fluorescent flagging tape cut to 36 in (91.4 cm) lengths was inserted through the anterior base of the dorsal fin.

Sockeye salmon were marked with the flag tags on two occasions. The first group of 80 was tagged on 6 July and thought to represent fish at the peak of the run. In actuality this was the tenth day accounting for only 22% of the total run though 41% of the escapement. Given a finite lag estimate of 11 days, 6 July had an escapement of 13,000 sockeye salmon, 0.6% of which were tagged. Six July was also a Monday on which the fishing period began at 9 a.m. Subsequently, 20% of those tagged were captured by the commercial fishery (Table 31). The second group was tagged 12-13 July, a 24-hour period spanning noon to noon, necessary

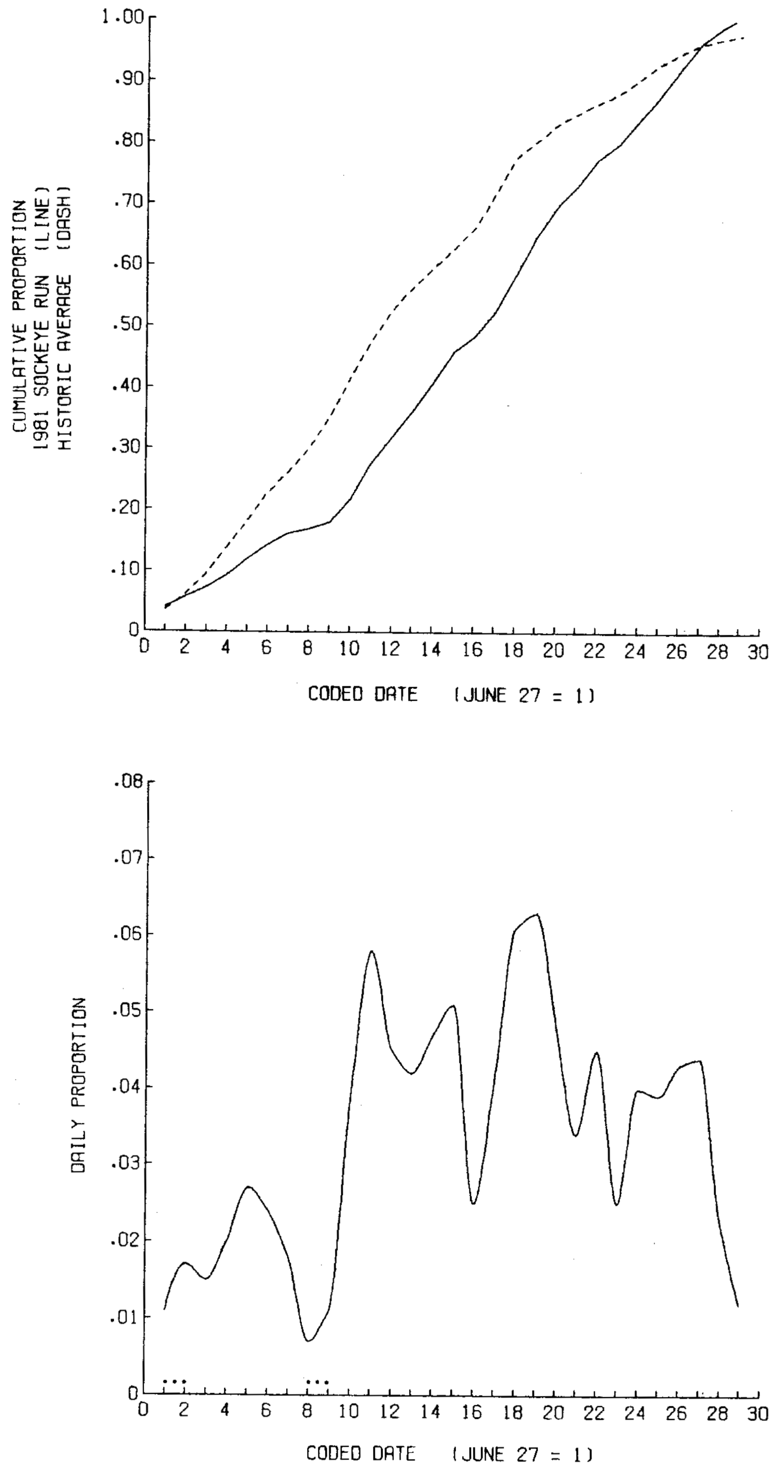


Figure 32. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1981, (...) represents periods closed to fishing.

Table 31. Summary of tagged sockeye salmon recaptured by the 1981 commercial fishery in Togiak Bay.

Tag Color	Date Tagged	Number Tagged	Number of Days Between Tagging and Subsequent Capture								Total Number	% of Total Release
			0	1	2	3	4	5	6	7		
Yellow	7/6	80	7	6	3						16	20.0
			0.5									
White w/ Red Dots	7/12-13	22		1							1	4.5
Total		102									17	16.7

Table 32. Summary of the 1981 tagging study of sockeye salmon in Togiak River.

Tag color	Date tagged	Number tagged	Number of days between tagging and subsequent sighting at the tower										Total sighted	% of Total	Average travel time	Examination time (%)
			5	6	7	8	9	10	11	12	13	14				
Yellow	7/6	80		2		1		3	1				7	8.8	8.7	16.0
			5.5			8.5			11.5	12.5						
White w/ Red Dots	7/12-13	22	1			1			1	1			4	18.2	9.5	16.0
Total		102											11	10,8	9.0	16.0

for daylight access into the estuary which was possible only at high tide. Twenty-two fish were tagged on this 16th and 17th day of the run where 48-52% of the run had been accounted. Again, an 11-day lag indicated an escapement of 8,000 fish present where less than 1% were tagged. Only one was subsequently recaptured by the commercial fishery (Table 31) though the district was open to continuous fishing.

Only 8.8% of the first group tagged were sighted by personnel at the counting towers. Given that counting occurs on each bank for only 10 minutes out of every hour, 52.8% of those tagged were accountable. The travel time averaged 8.7 days (Table 32) with a range from 6 to 11 days. A similar range was observed for the second group, being 5.5 to 12.5 days with an average of 9.5 (Table 32). The ranges are in agreement with the tagging study done in 1966 by ADF&G (Pennoyer and Nelson 1967). For that year, the range of travel times as sighted by the counting towers was from 7 to 18 days with an average of 13.3 days. The travel time of 1981 also agrees in range with the curve matching at 10% which found a lag of 7 to 9 days. In contrast, the minimum of variance of catchability occurred with a lag time of 11 days.

DISCUSSION

Methods

The continued success of the Togiak Bay sockeye salmon model will be judged by its usefulness to the regulatory body in future applications. Yet, the close estimation of the 1981 season and the good statistical fit of the developed regression models supports the appropriateness of the assumptions being made within the framework of a predictive model. It was successful in that after 2 July cumulative escapement estimated from the model remained within 18% of the tower counts.

Two primary assumptions were incorporated into the development of the Togiak fishery model. The first assumed a 1-day retention period for sockeye salmon in Togiak Bay. It was subsequently shown that its violation would be detected in catchability becoming a function of effort (see page 15). In addition, within the discussion of variance components of catchability, several plausible behavior mechanisms within the commercial fishery were presented which could also account for this relationship without the retention period being greater than 1 day. Both the function discussed in model derivation and those describing behavior of the fishery indicated a decrease in catchability within an increase in effort. Not surprisingly effort was found to describe a large portion of the variance in catchability. It could not be determined at that time if the relationship was due to the retention period or commercial fishery behavior. Later, within the discussion of the estimation of total abundance it was demonstrated how a retention period greater than 1 day and noncontinuous fishing would affect the reconstructed entry pattern. The type of sine-soidal pattern produced was very similar to that observed in Togiak. Finally, observations of the ADF&G area management biologist suggests that some portion of the fish stay in Togiak Bay longer than 1 day. In summary, evidence from this study indicates a retention period greater than 1 day, though only a program designed to quantify fish movement would document this occurrence. The model to estimate daily escapement has incorporated a response to the violation of this assumption by allowing catchability to vary with the level of effort. To avoid the necessity to solve for three unknowns (see page 15), a regression of catchability versus effort was fit to historical data.

The assumption of a constant lag time was also used throughout the study. Tagging was difficult because of the low volume of passage and restricted access to the estuary, thus adding little additional data for determining a distribution of travel time. Though a distribution has been shown to exist, the constant lag viewed as the mean of the distribution has been sufficient for this predictive model. The next step in such research would be to incorporate a travel time distribution and determine if any improvement in prediction results. Research would be needed to define a travel time distribution from existing data of other areas or conduct additional tracking experiments. It would also be advisable to determine if a travel time distribution is in any way responsible for the sine-soidal entry pattern demonstrated for Togiak sockeye salmon.

During the development of daily catchability from historical data it became evident that variability existed within and between years. The literature suggested several sources for the variance of catchability observed in a commercial fishery. Several of the easily quantifiable variables were evaluated for the Togiak Bay sockeye salmon fishery. Level of effort dominated all relationships with catchability before and after blocking on time. Other variables as a tide index and landings per boat were too highly correlated with effort to be useful. Effort in landings provided the best fit to the data with the highest coefficient of determination (R^2) and boats per day as effort were not used past the investigation. No variable representing fish size was consistently significant for the Togiak data. This may be due in part to the available unit of effort and data collection such that the relation is at best detected only when other variables affecting effort and catchability are held constant as in a test fishery. In addition, the mean fish size differed little between years in the historic data set and selectivity curves were quite flat over a wide range of lengths. Another variable, day of run, was initially significant for data of all years pooled and indicated a later analysis scheme. When the data were broken into weeks for separate regressions, only the fourth week retained a significant time trend. As postulated for justification of blocking by week, the fourth week was thought to be influenced by the initiation of later timed runs bound for Togiak tributaries and the main river channel below the counting tower. If day of the run continues to be a significant variable upon the inclusion of 1981 data the model of the fourth week may be modified to include this variable.

As noted in the presentation of the 1981 total run estimates and the resulting entry pattern, this season deviated substantially from the historical average. It built slowly and for the second year in history there was continuous fishing for most of the season. The importance of knowing the departure rate of sockeye salmon with a retention period greater than 1 day which is exploited in a noncontinuous manner was demonstrated in model development (see above section on Total Run Estimation). It would appear in Togiak that further refinement of the use of migratory time-density function could only follow a fuller understanding of fish movement and the interaction with the commercial fishery. The reconstructed entry pattern is very sensitive to the pattern of fishing and the stay of fish in the bay. Lastly, the use of a migratory time-density function relies on the consistency of the entry pattern. In Togiak the entry pattern was postulated to be a function of the arrival pattern, departure pattern, and the fishing periods.

Results of Model Usage in 1981

The 1981 Togiak Bay sockeye salmon fishery was consistently conducted at levels of effort near the uppermost range of historical data. This affected the model in that when dealing with a regression equation it may not be valid to extrapolate beyond the uppermost level on which it is based. In addition, confidence limits about a regression line increase in width as one moves away from the mean. Thus, the variance of catchability increases as effort increases beyond its mean. Each week's model to estimate catchability was based on a mean effort of 112 to 120 landings where only 18 data points provided information on behavior at greater than 160 landings. The 1981 season saw the level of effort in this range for 14 days. In addition, 7 July and 23 July dictated extrapolation of the models to new levels of effort with a resulting low percent error between escapement estimated and the tower counts supporting this choice of model.

When finalized catch and effort data from fish ticket processing becomes available for 1981 it will be incorporated into the historical data set and new weekly regression equations will be developed. Only the power curve will continue to be considered where it was the preferred model this year. The addition of several points at the extreme will strengthen behavior at the upper levels of effort. At the other end of the scale it was noted that for days where effort was below 100 landings the power curve model again provided estimates with the lowest error.

The performance differed for each weeks model in estimating escapement for Togiak Bay sockeye salmon. The first week saw an initial underestimation of escapement though ending with a cumulative estimate with an error of -7%. It appeared that the chum salmon *(Oncorhynchus keta)* run was early in relation to the sockeye salmon run. Normally during the first week of the sockeye salmon run there are an average of 6.9 sockeye per chum salmon caught. Exceptions being in years of extremely low sockeye salmon runs as in 1972 which averaged 1.7 and abnormally timed runs as in 1978 averaging 1.8 sockeye per chum salmon. In 1981, the first week of fishing, 29 June to 3 July, averaged 1.4 sockeye per chum salmon with an increasing trend through the week beginning with 0.6 on Monday. This was accompanied by a trend of decreasing underestimation beginning on Monday. There is the question of gear saturation by chum salmon or a change in species interaction from the previous years affecting model behavior which had not been addressed in its development. The only weekend closure for which escapement could be estimated fell on 4 and 5 July. Here the interpolation function behaved well; Friday's estimate was off by 30%, the resulting interpolated estimate was off by only 13%.

The second week of the run was from 5 July to 11 July. Again using the appropriate interpolation function Sunday's escapement was estimated from Monday's with a larger error than the previous day. This is to be expected as the original regression had a lower R^2 value than that used on Saturday (Table 17). During this week daily escapement was consistently overestimated. Yet historically this week has been plagued with processor limitations resulting in catch limits for fishermen and at times cessation of buying. This would artificially decrease catchability and data would have a downward bias. In contrast, no limitation was observed this year which may be due in part to improvements made by the processors such as installation of additional offloading cranes, or increased freezing capabilities. The largest land-based processor was able to handle this year's catch with little delay while in 1980 restrictions occurred with a lower catch. Thus, during the 1981 season catchability was not artificially depressed and the catchability coefficient was consistently underestimated with the resulting escapement being overestimated. Incorporation of 1981 data will greatly improve the model for 1982, where if the run is at or below forecast, processor limitations should not occur. These limitations are thought a temporary phenomena in that run size doubled in 1978 and remained about that level thereafter, resulting in a lag in improving processing capabilities which may have ended this year.

During the third week, daily escapement was consistently underestimated. Large effort again tested the model's behavior at the tail where catchability was slightly overestimated. Incorporation of 1981 data into the historical model may stabilize this range where previous year's data (Figure 13) have predominantly been above the regression line. The model did reflect the drop in escapement seen by the towers during the fourth week of the run. No discernible time trend was indicated this year which would necessitate the inclusion of day of the run into the model. Only in the last 4 days was there an increasing trend in the positive error of escapement estimates.

In summary, estimation of escapement for the 1981 Togiak Bay sockeye salmon run was successful in that it was used by the regulatory agency in judging fulfillment of the escapement goal. The decision to open the Togiak District to continuous fishing effort after 10 July would have incorporated the information on estimated escapement not yet verified by the towers as no aerial surveys were flown this year. As the model for estimating catchability is based on regression analysis one would expect (assuming a normally distributed error) for a true value of catchability to occur above or below the regression line with equal likelihood. One would also expect daily escapement values to vary about the estimates such that an accumulation of the estimates should better describe cumulative tower counts than daily comparisons, as negative and positive errors cancel. The power curve model for estimating catchability will be used in 1982 upon incorporation of 1981 data.

The post-season analysis of the 1981 data resulted in a lag time of 11 days. The variance of catchability was minimized with this value though it was out of range of the 7 to 9 day lag derived from matching catch and escapement curves at the 10% level. This discrepancy should be viewed in reference to the large escapement during a weekend closure encompassing day one of the run. The catch and effort curves were not even parallel this early in the season reconfirming the qualitative nature of curve matching in this application. Ten percent of the total escapement entered the river on that first weekend closure (27 and 28 June) to pass the counting tower 8-9 July. Had continuous fishing occurred these would not all have escaped and perhaps an 11-day lag would have been approached. Continuous fishing substantially altered the fishing pattern, creating a slow buildup of catch with a weekend closure the first 2 weeks of fishing. Thus, more weight is given to the second half of the season for the catch curve which is in contrast to the faster buildup of escapement in response to the weekend closures the first half of the season.

Lag time was independently derived from a tagging experiment in Togiak River. The average travel time was 9 days (Table 32), though the low percent sighted by the towers diminishes the precision of the results. Again a travel time distribution was observed with a range of 5.5 to 12.5 days. Before direct application of these results it would be necessary to know how this sample represents the true population. A large proportion of those tagged in the first group were subsequently recaptured by the fishery (Table 31) and it could be due to differential stress by size because of capture by a gill net. There may be a greater probability of gill damage to a small fish than say a large male snagged only by its jaw. It is most likely, this sample mean travel time represents a faster fish than the population average.

Additional Application of Togiak Modeling Techniques

The usefulness of the Togiak fishery model in estimating daily escapement of sockeye salmon into the Togiak River can be attributed to three key components of the system. The most important has been the stability of the fishing fleet which has facilitated the prediction of future catchability based on historical data. The composition of the commercial fleet has not appeared to change dramatically these last few years. Any trend has been gradual and may be the result of replacement of old gear and machinery. If a trend exists with an accompanying trend in efficiency it would suggest that the inclusion of each year's data should be accompanied by an evaluation of the continued unweighted inclusion of the oldest year of the data set. This could be accomplished within the regression analysis for catchability and effort in that equations with and without the oldest data are compared along with an appropriate weighting scheme.

Another key component in the Togiak system is the length of the normal fishing period being 9 a.m. Monday through 9 a.m. Friday. Initially this has minimized the need to interpolate for closed periods. In addition, the success given the use of a constant mean lag time may be due in part to the extended fishing periods. Here each travel time distribution was represented by its mean where faster fish became incorporated into the previous day's tower count and slower fish into the following day. The slower fish of day i are cancelled by the faster fish of day $i-1$ and where the two are not equal, variance in catchability may result. With extended fishing periods, more days are incorporated into the CPUE model allowing for cancellation of a greater range of swimming speeds. Basically, the extended fishing petiod may have compensated for the use of a constant lag time as sampling by the fishery is occurring nearly every day.

The last component involves the daily enumeration of a large proportion of the stock after a relatively unobstructed upriver migration. It seems logical that the shorter the distance to enumeration the less time available for a spread between migrating fish to develop and the more appropriate a constant lag. The lag time for Togiak River was large for Bristol Bay, averaging 11 days. Yet no lagoon or holding area existed which could substantially change the pattern of migration and dampen the effectiveness of a reconstructed entry pattern necessary in defining catchability. Finally, there was no evidence of the upriver migration behavior being affected by the magnitude of the run in that the lag time within the model appeared unrelated to total escapement. In contrast, the smallest interval of time for which escapement counts are available may become a limiting factor given that a sufficient proportion is enumerated. If historically the smallest interval for an escapement estimate was a week, then in using these techniques escapement could only be estimated in-season by week. Systems with only final enumeration must then rely on different assumptions for any finer estimate than a total. A daily catchability function cannot be developed without a daily entry pattern. A constant catchability would need to be assumed or total escapement apportioned in some manner over the season. Yet results of this study strongly indicate the need for a catchability function which in this case involved the level of effort.

The continued use of the Togiak fishery model will be contingent on the yearly update of the data set upon which the catchability function is based. Incorporation of each year's data becomes paramount. Users must be sensitive to a significant pattern of deviation of the recent year's data which could indicate a breakdown of the model in a rapidly changing system. In addition, a gradual trend in efficiency could dictate the exclusion of the oldest data as catchability is a dynamic concept. The predictive nature of the model allows the incorporation of new relationships, or data as available or applicable. It could be modified to incorporate a travel time distribution which would involve development of a different historic daily abundance schedule as escapement would not be apportioned as the daily tower counts. Additional variables should be tested continuously and incorporated if a functional relationship is demonstrated through research or if they become a significant factor in the regression analysis for catchability. Differently shaped models may also suggest themselves as additional data becomes available, resulting in a better fit.

The methodology involved in the Togiak Bay sockeye salmon model may be applied to other areas or species. Direct application would be assumed in a system with the key components of a stable fishing fleet, extended fishing periods, and daily escapement counts which retain the marine departure pattern. The salmonid species itself would not be critical if the before-mentioned components were present and additional attention was paid towards its particular interaction with the gear present. In example this study did not deal with a purse seine fishery or a mixed fishery with gill nets. Again a different species or stock could have a differently shaped selectivity curve indicating some effect on catchability.

Lastly, in a system where the methodology could be directly applied but where escapement estimates are already provided by a test fishery, another approach could be taken. Here in-season simulation could be done in that catchability is derived from historical data as in this study. In-season, instead of estimating escapement one could simulate the time necessary for varying harvest levels given knowledge of effort present, incoming run strength and a historic catchability function. This would allow managers to test what effect different length openings would have on the system with the goal being attainment of a predetermined escapement.

SUMMARY

1) Catch per unit effort from the commercial sockeye salmon fishery in Togiak Bay, Alaska had not previously been related to standing stock in a rigorous manner. It was proposed for the Togiak system that the temporal regularity of fishing periods, the apparent relative stability of effort, and the large percentage of the escapement enumerated on a daily basis should accommodate the use of CPUE in estimating daily abundance and total returning stock while the fishery is in progress.

2) Togiak River sockeye salmon were found to take an average of 11 days to pass counting towers after leaving Togiak Bay. This created a gap for current cumulative escapement estimates which had previously been filled by aerial survey estimates of fish in the river below the counting towers. It was proposed that daily escapement could be estimated as the difference between daily abundance and catch. Daily abundance was derived as a function of daily CPUE and a catchability coefficient.

3) The catchability coefficient was derived from historical data and was found to vary within and between years. Several variables which were suggested by the literature could cause such variance. It was hypothesized that substantial variation could be explained by these variables. Catchability could then be derived in-season and used with CPUE to estimate daily abundance. Daily level of effort was the only variable consistently significant and explained on average 79% of the variation.

4) Total returning stock was estimated as the ratio of cumulative return to date over the expected proportion returned to date. The expected proportion was provided by a migratory time-density function derived as a historic average across years by day of run for the cumulative proportion curves of Togiak Bay sockeye salmon catch plus escapement. It was postulated that a given year's reconstructed entry pattern was affected by the arrival of sockeye salmon into the area, retention of fish in the bay, and the timing of the fishing periods.

5) The above results were incorporated into a management model for Togiak River sockeye salmon which provided a schedule of daily escapements and total run size estimates during the season. The model was tested during the 1981 season.

6) The management model was successful as the model's cumulative escapement estimates differed from the tower counts by less than 18% (relative error) after 1 July 1981.

7) Total run size was consistently underestimated during the 1981 season with an error of up to 30%.

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I would like to thank Drs. Ole Mathisen, John Clark, and Robert Francis as members of my supervisory committee for their counsel and support. The original idea for the study came from Dr. Mathisen with this vast experience in the Bristol Bay area. In addition the decision to fund such research was made by Dr. John Clark. His support has been instrumental in gaining the assistance I have received throughout the Alaska Department of Fish and Game. I also thank Dr. Phillip Mundy for adding greatly appreciated insight at several stages of the research.

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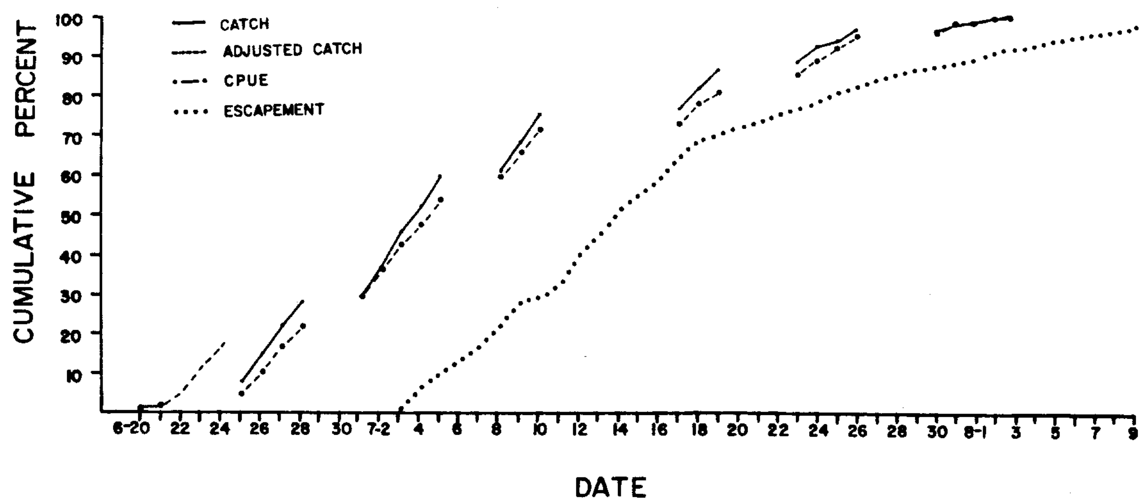
APPENDIX A

Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery 1967-1980. Included are those not presented in the section on Proposed Model to Estimate Daily Abundance.



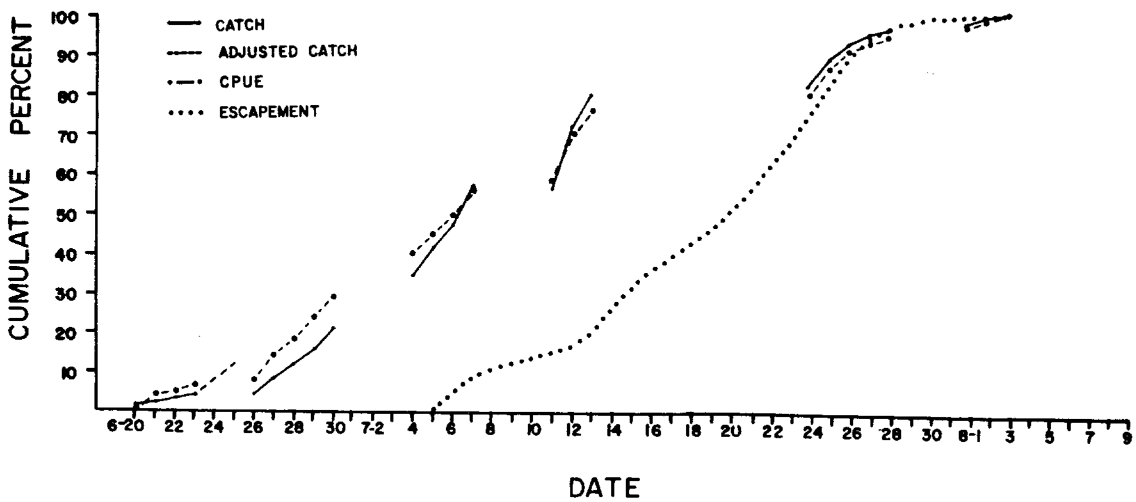


Figure A-1. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery: top - 1968; bottom - 1967.

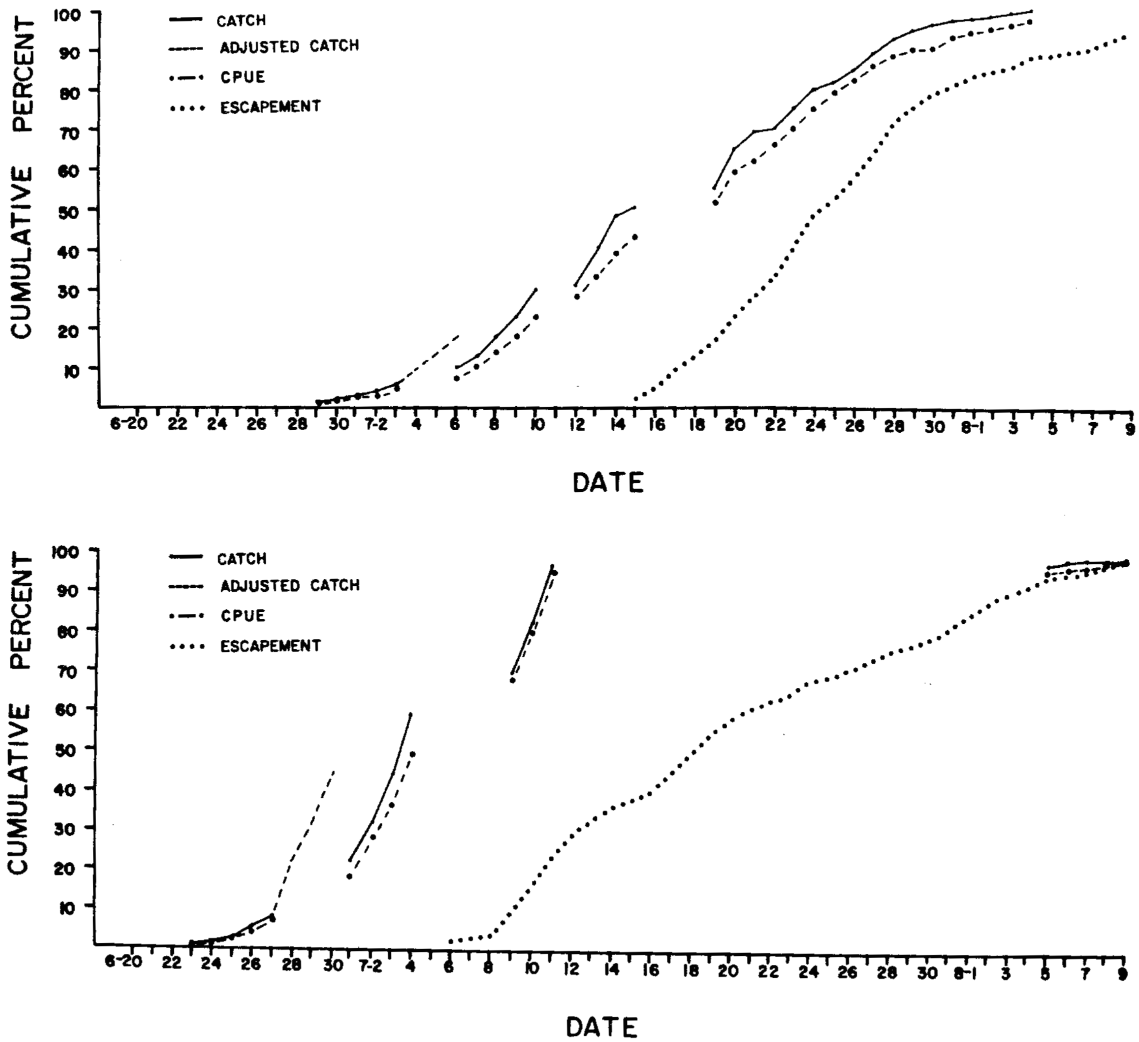


Figure A-2. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery: top - 1971; bottom - 1969.

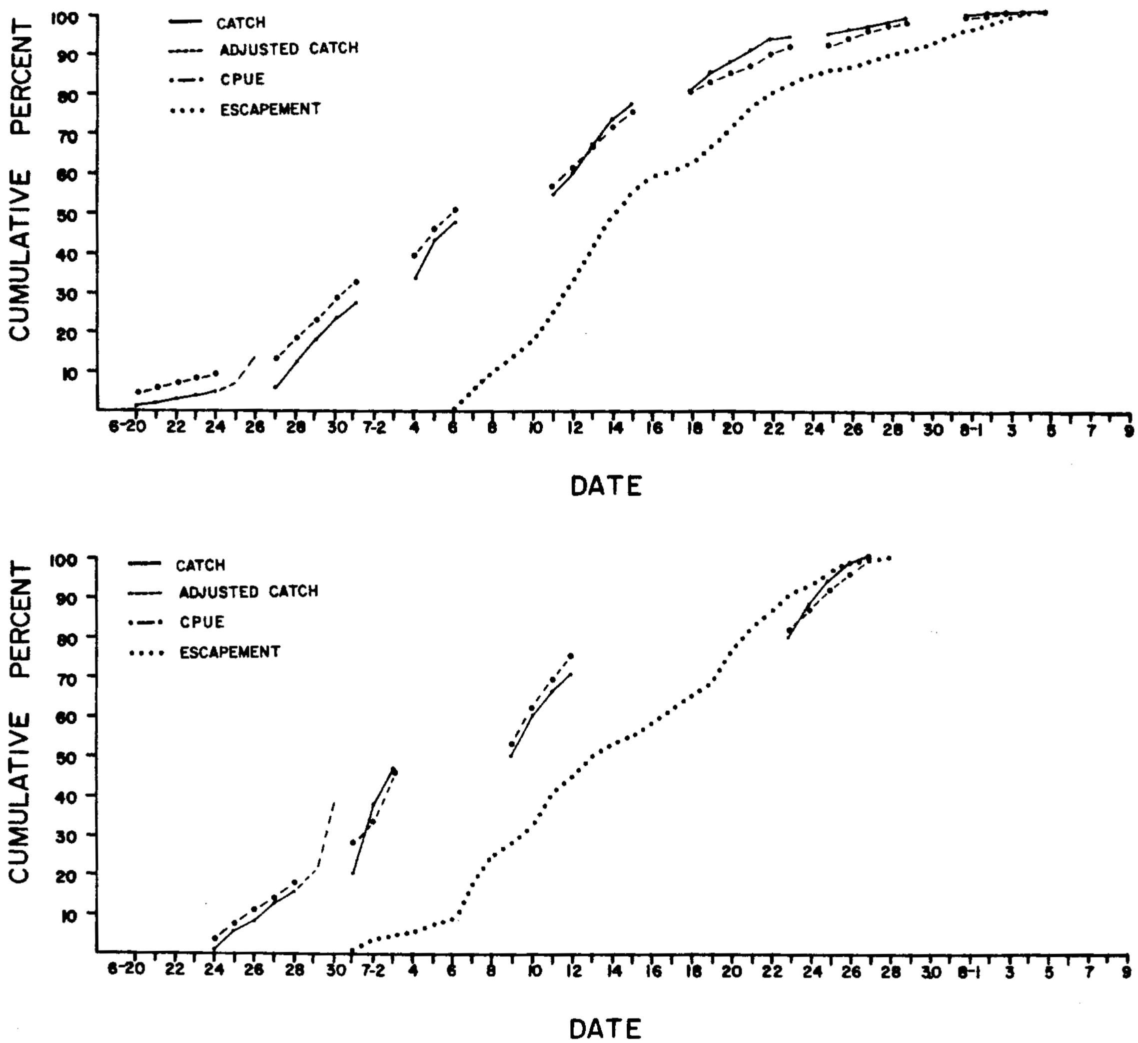


Figure A-3. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery: top - 1977; bottom - 1974.

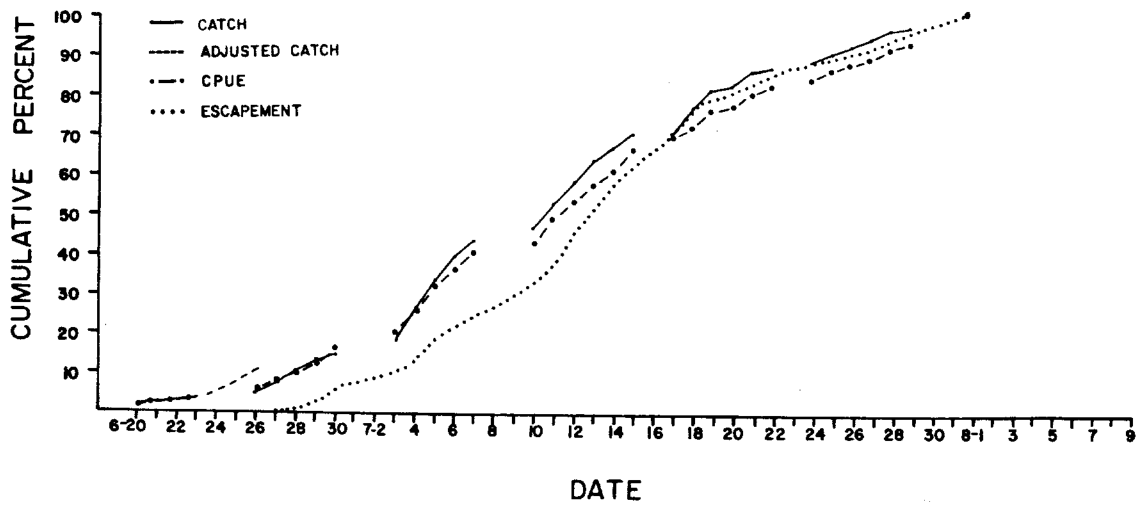


Figure A-4. Cumulative proportion curves for catch and escapement of the Togiak Bay sockeye salmon fishery, 1978.

APPENDIX B

Selectivity and exploitation by length curves for Togiak Bay sockeye salmon 1972-1974. Included are those not presented in the section on Proposed Model to Estimate Daily Abundance.

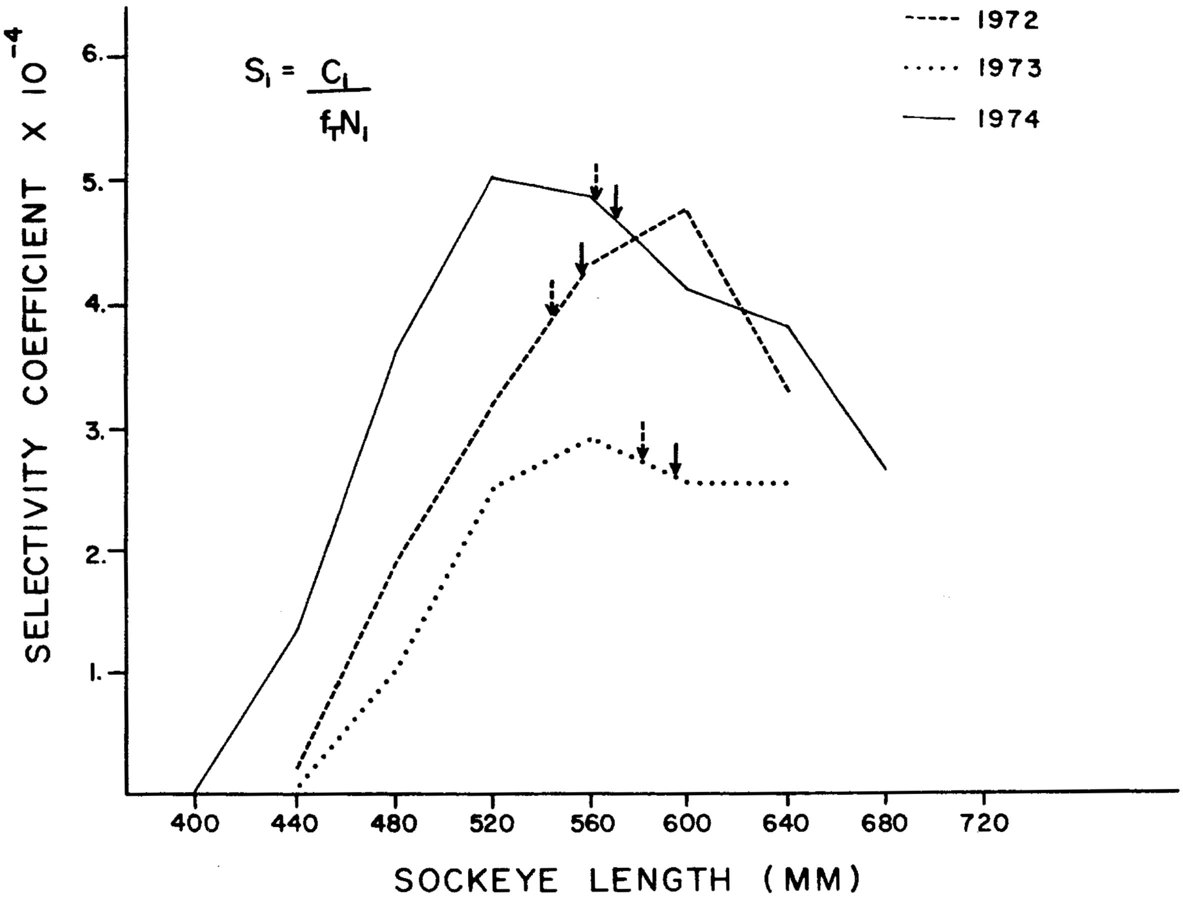


Figure B-1. Selectivity curves for Togiak Bay sockeye salmon, 1972-1974. Fish length is measured from mid-eye to fork of tail.

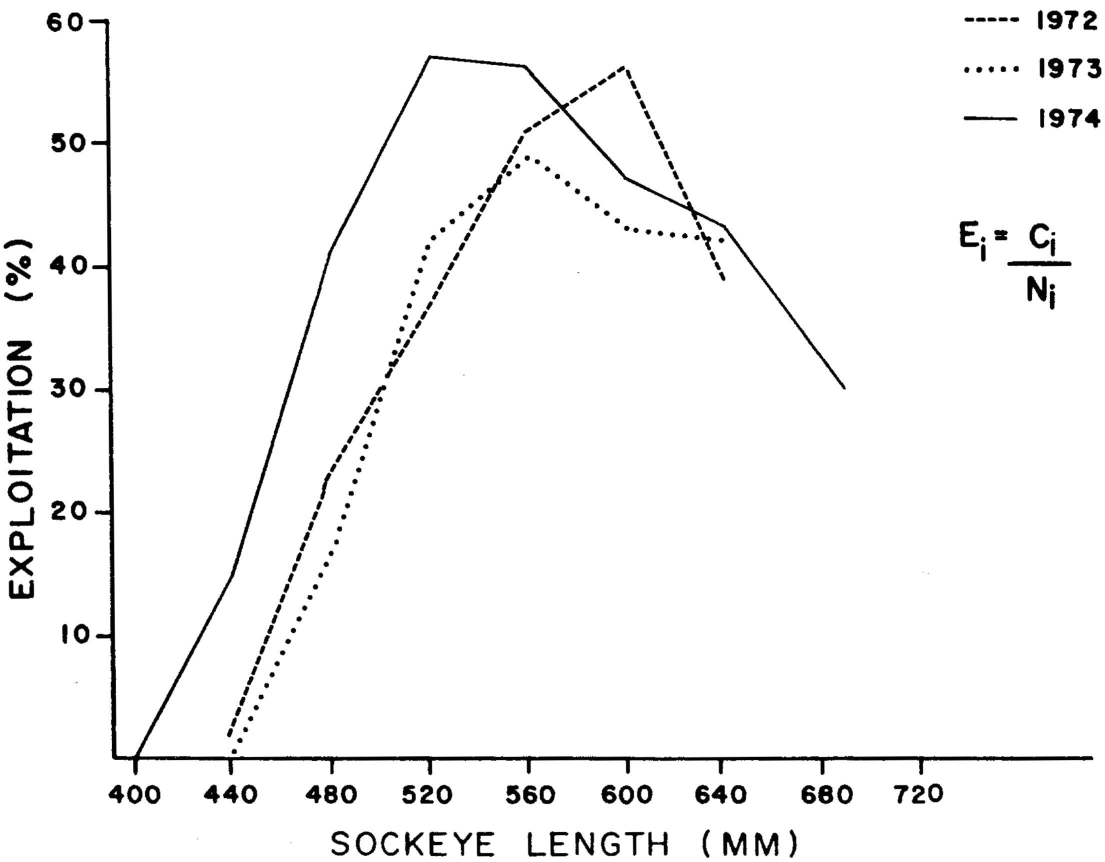


Figure B-2. Exploitation by length curves for Togiak Bay sockeye salmon, 1972-1974. Fish length is measured from mid-eye to fork of tail.

APPENDIX C

Cumulative and daily proportion curves for the Togiak Bay sockeye salmon run 1967-1980. Included are those not presented in the section on Total Run Estimation.

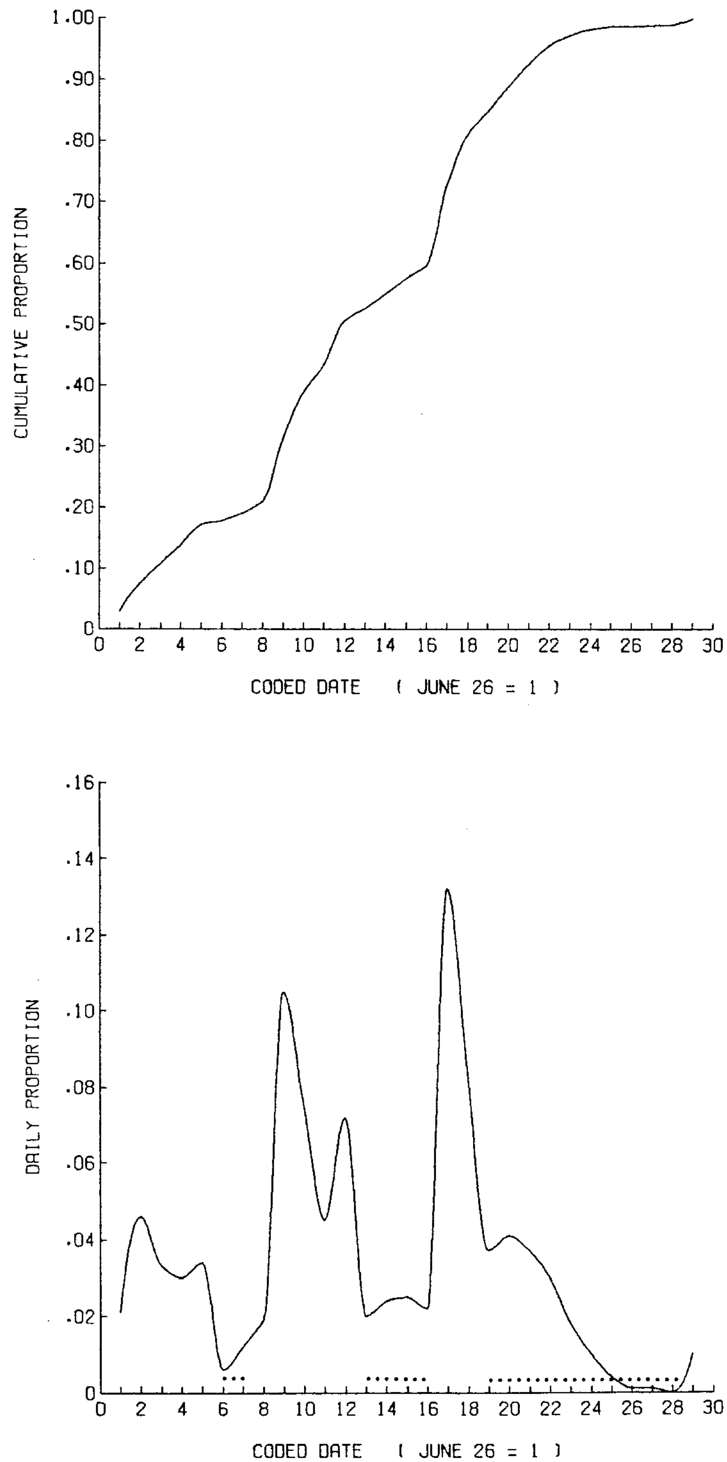


Figure C-1. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1967, (...) represents periods closed to fishing.

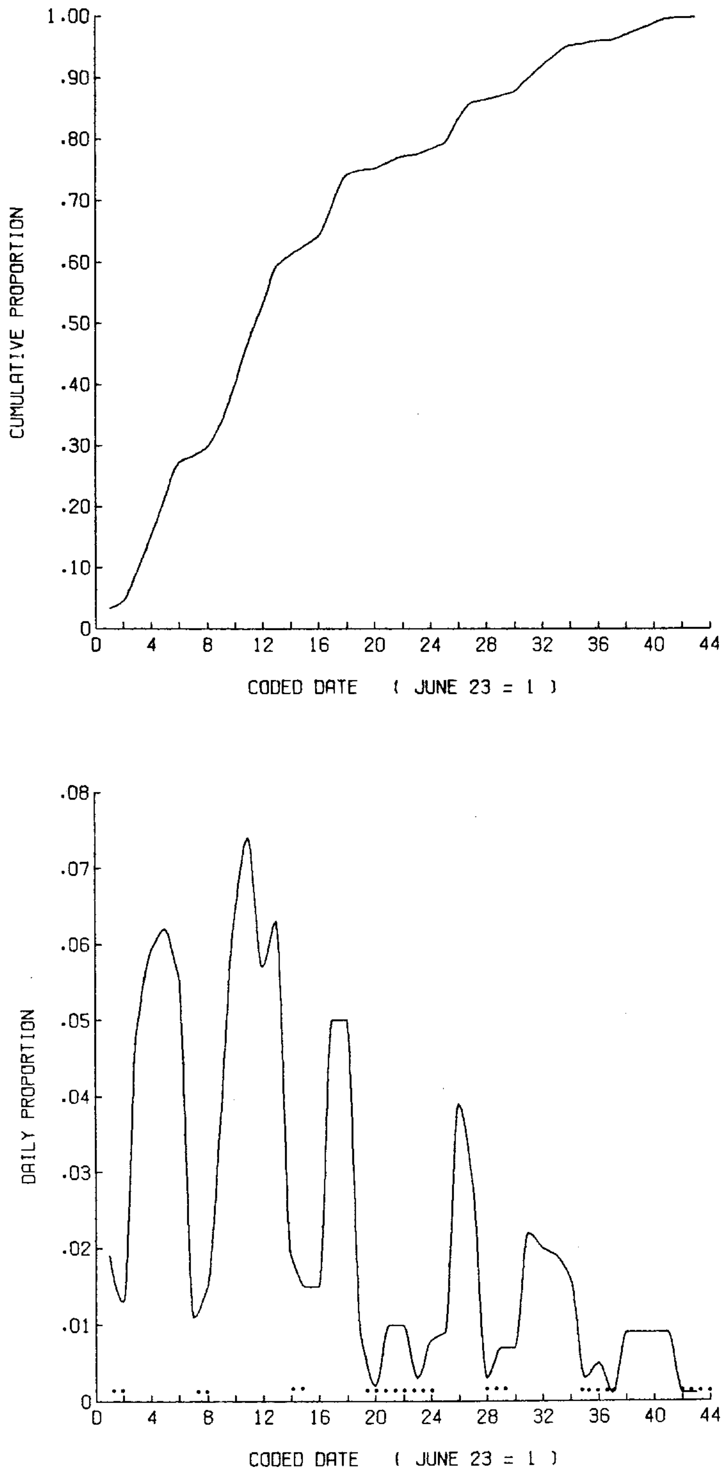
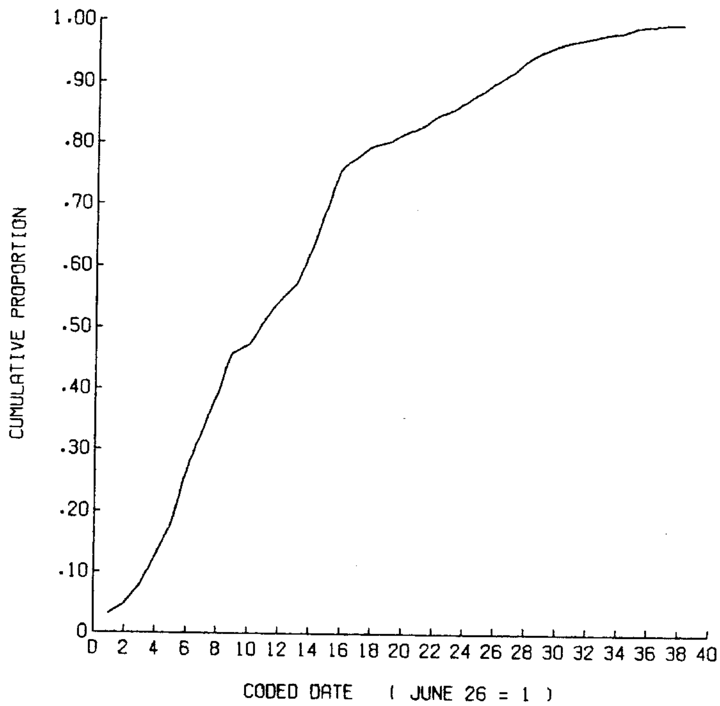


Figure C-2. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1968, (...) represents periods closed to fishing.



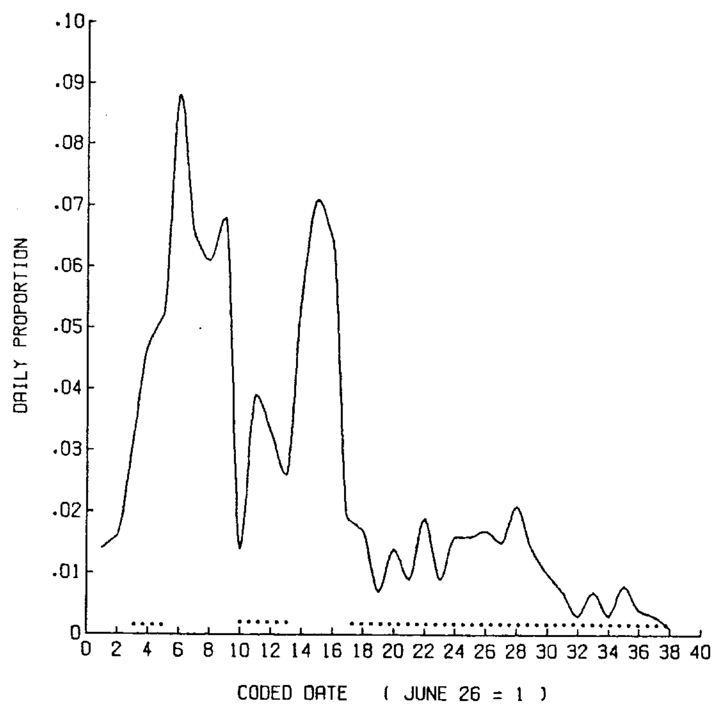


Figure C-3. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1969, (...) represents periods closed to fishing.

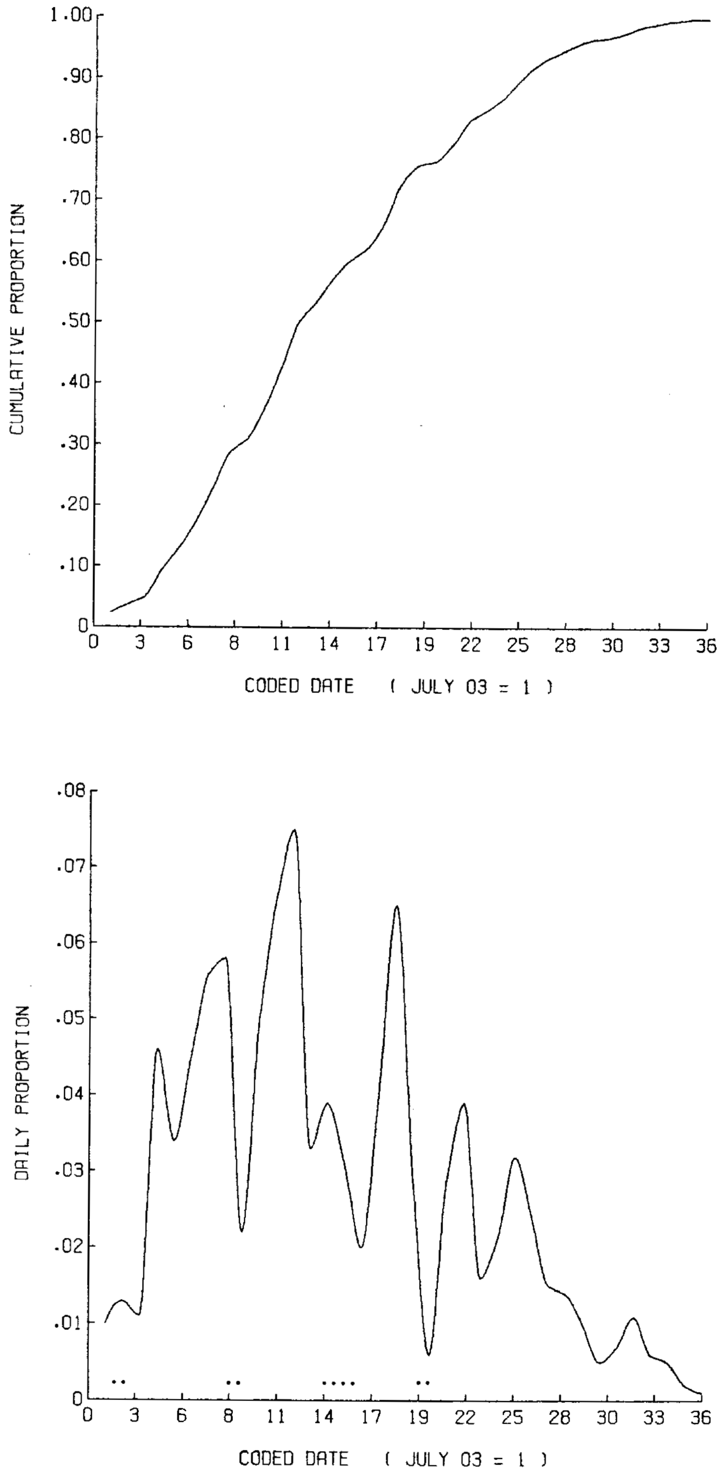


Figure C-4. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1971, (...) represents periods closed to fishing.

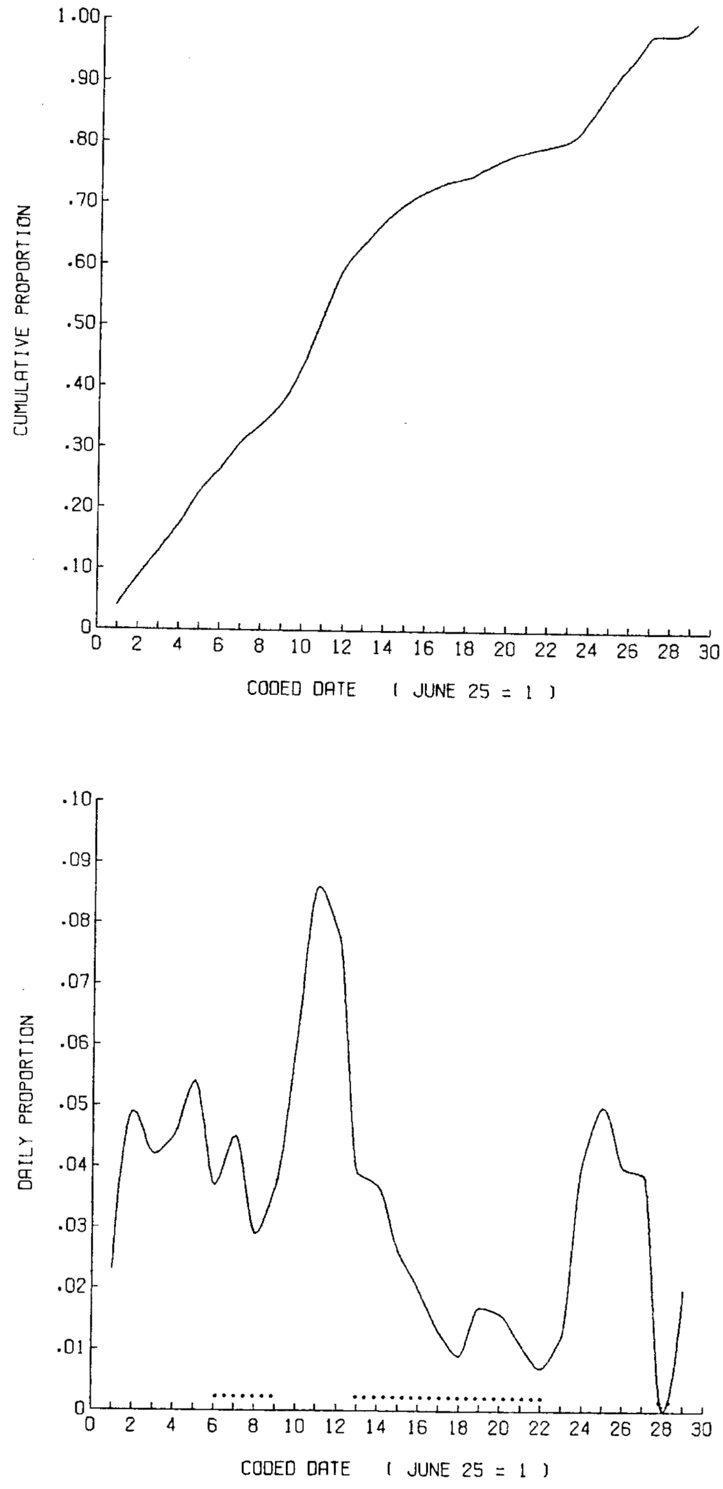


Figure C-5. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1973, (...) represents periods closed to fishing.

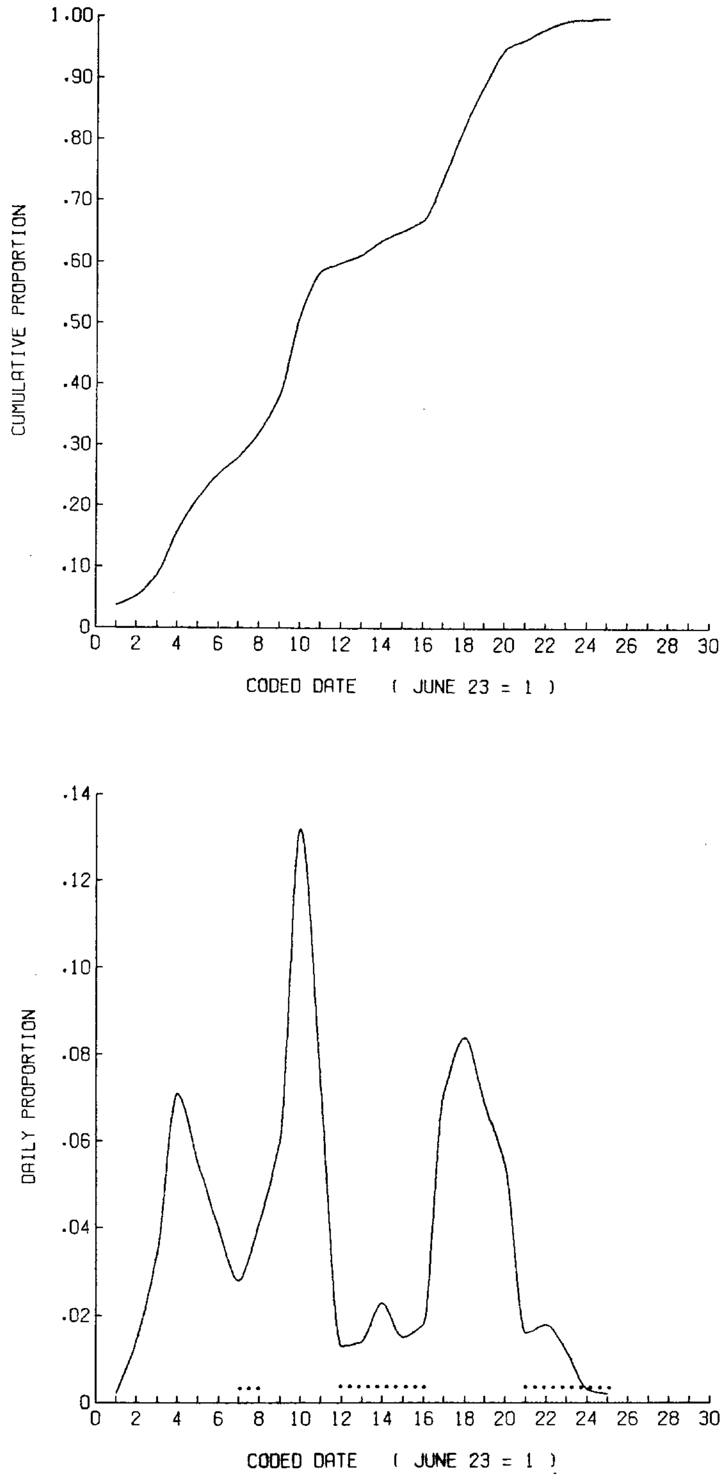


Figure C-6. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1974, (...) represents periods closed to fishing.

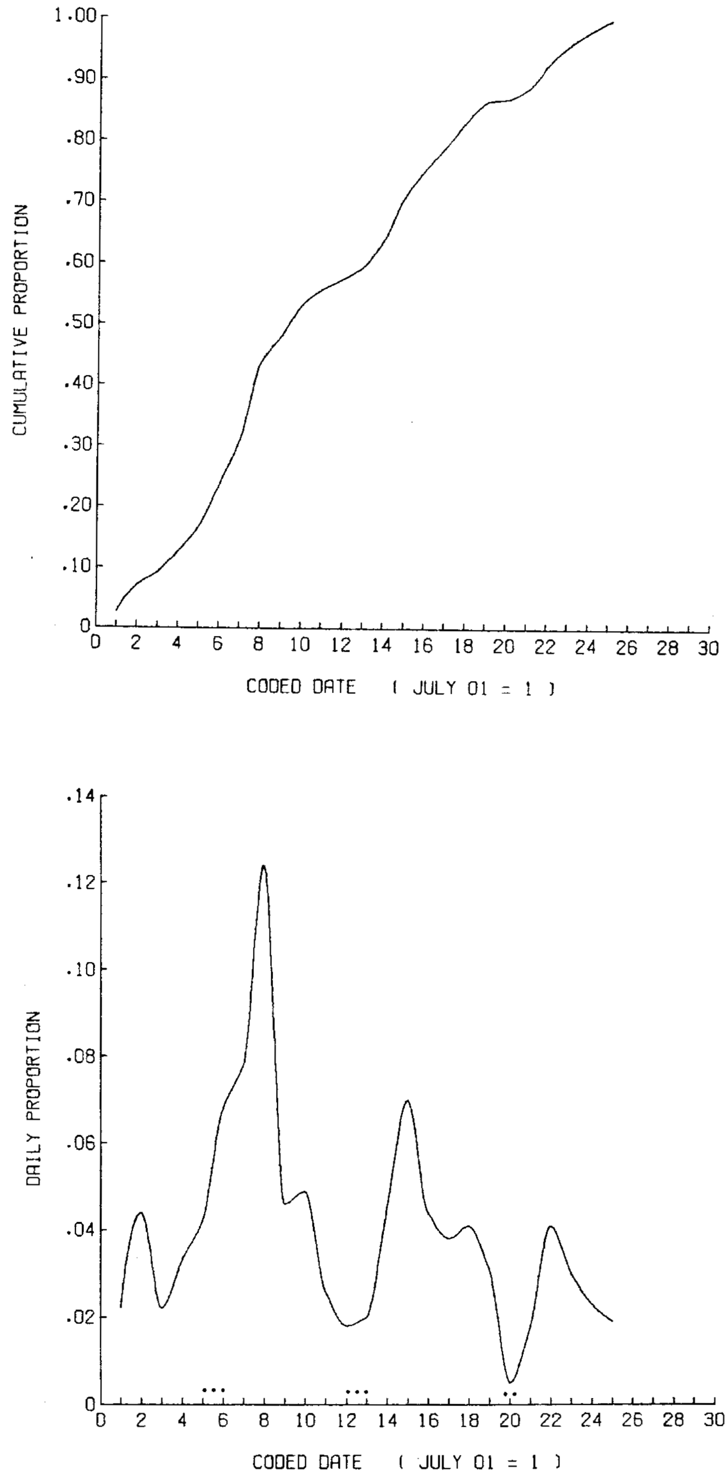


Figure C-7. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1975, (...) represents periods closed to fishing.

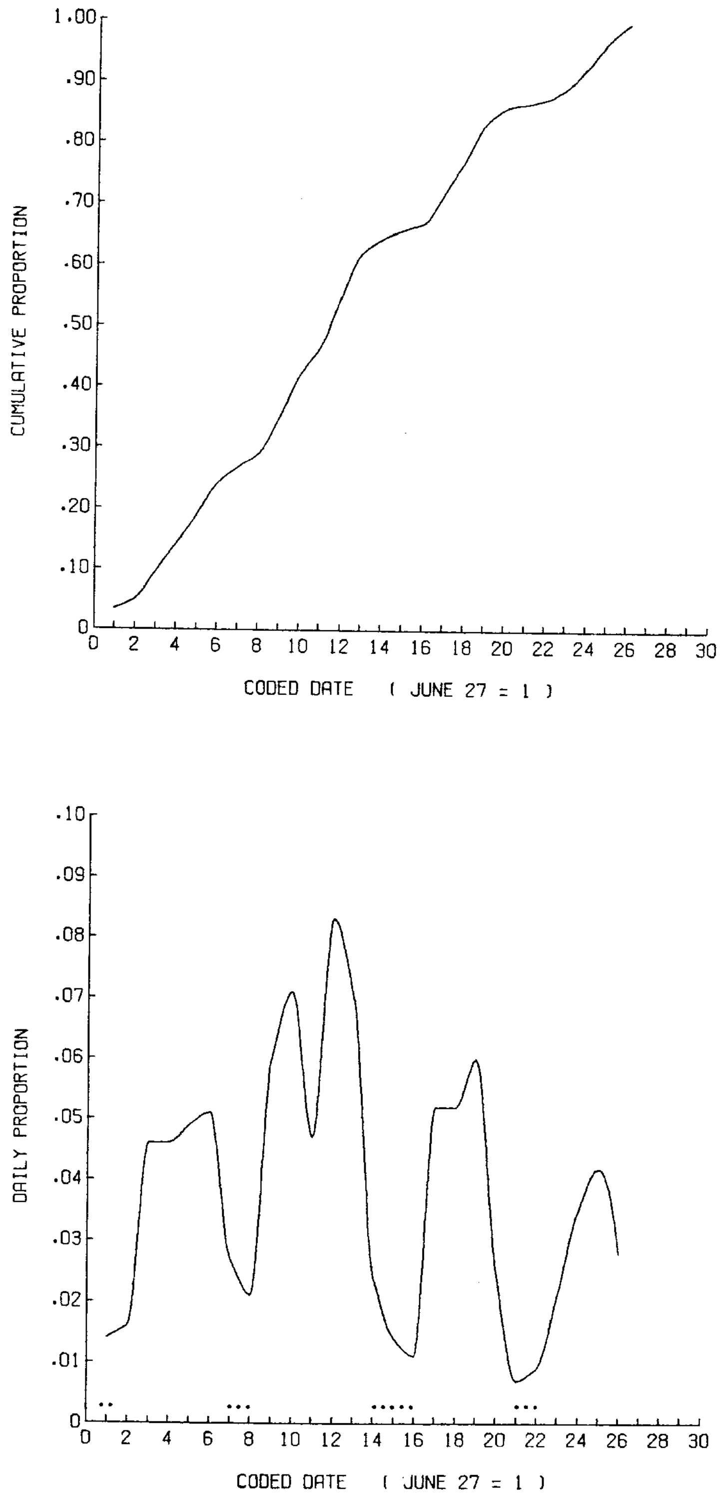
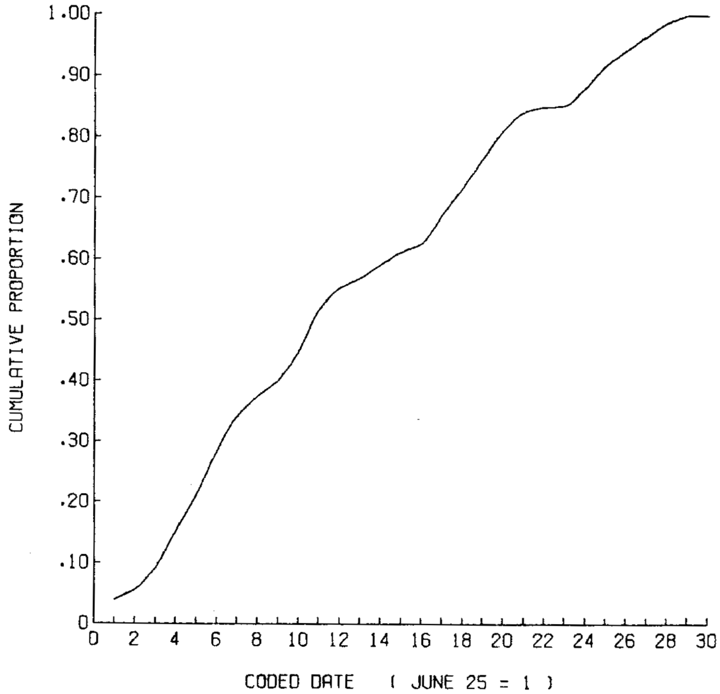


Figure C-8. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1976, (...) represents periods closed to fishing.



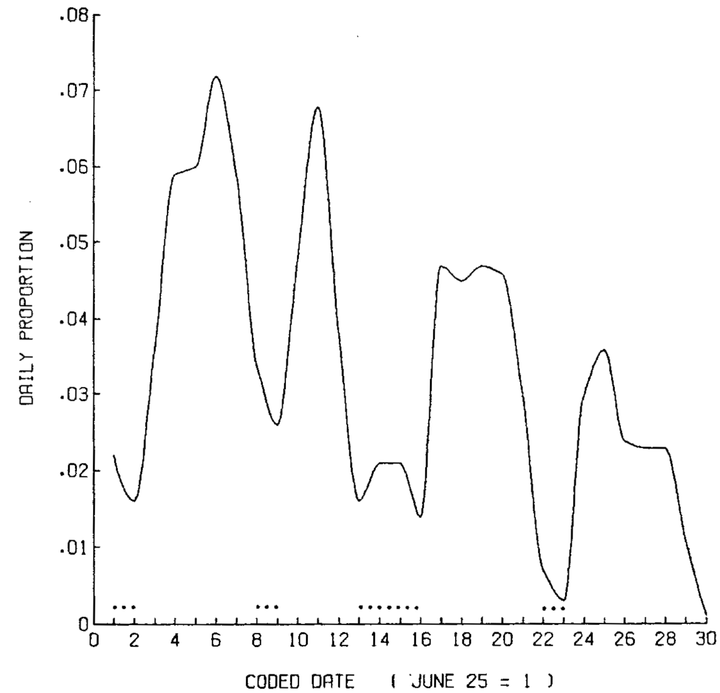


Figure C-9. Cumulative (top) and daily (bottom) proportion curves for the Togiak Bay sockeye salmon run of 1977, (...) represents periods closed to fishing.